



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**DEVELOPMENT OF INTEGRATED 3D TERRAIN MAPS  
FOR UNMANNED AERIAL VEHICLE (UAV) FLIGHT AND  
MISSION CONTROL SUPPORT SYSTEM (FMCSS)**

by

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March 2006

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SYSTEM (FMCSS)**

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## **ABSTRACT**

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## LIST OF ACRONYMS

2D	Two-Dimensional
3D	Three-Dimensional
ADL	Alexandria Digital Library
ADRG	ARC Digitized Raster Graphics
AMT	Automated Motion Tracking
ASCII	American Standard Code for Information Interchange
ATT	Automated Target Tracking
BFS	Biometric Fusion Center
BIIF	Binary Imagery Interchange Format
BV	Battlefield Visualization
BMP	Bit Map
COP	Common Operational Picture
COTS	Commercial-Off-the-Shelf
CR	Camp Roberts
CT	Coordinate Transformation
CTDB	Compact Terrain Database
DARPA	Defense Advanced Research Projects Agency
DCX	Digital Chart Update Manual
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DIF	Data Interchange Format
DMA	Defense Mapping Agency (see NGA)
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DRG	Digital Raster Graphic
DRM	Data Representation Model
DRT	Direction Finding Payload
DTAD	Digital Terrain Analysis Data
DTED	Digital Terrain Elevation Data
DTM	Digital Terrain Model
DVD	Digital Video Disk
EPT	Effective Performance Time
FMCSS	Flight Mission Control Support System
FTP	File Transfer Protocol

GIF	Graphics Interchange Format
GIS	Geographic Information System
GPS	Global Positioning System
IED	Improvised Explosive Device
IG	Image Generator
IMS	Information Management System
ISO	International Standards Organization
ITT	ITT Aerospace, Communications Division
JSIMS	Joint SIMulation System
JTASC	Joint Training, Analysis, and Simulation Center
JWARS	Joint WARfare System
LandSat MSI	Land Resources Satellite Multispectral Imaging
LRV	Light Reconnaissance Vehicle
LOS	Line-of-Sight
M&S	Modeling and Simulation
MCSS	Mission Control System Support
MIL-STD	U.S. Military Standard
MMALV	Morphing Micro Air-Land Vehicle
ModSAF	Modular Semi-Automated Forces
MOVES	Modeling, Virtual Environments, and Simulation
MRTDB	Model Reference Terrain Database
MSRR	Modeling and Simulation Resource Repository
M&S	Modeling and Simulation
NIMA	National Imagery Mapping Agency
NLOS	Non Line-of-Sight
NOC	Network Operations Center
NPS	Naval Postgraduate School
NTSC	National Television System Committee
ONC	Operational Navigation Chart
PC	Personal Computer
PCS	Projected Coordinate System
PDA	Personalized Digital Assistant
Pelican	Surrogate UAV (manned aircraft) from NPS CIRPAS
PVNT	Perspective View Nascent Technologies (software)
PBM	Portable Bit Map
PGM	Portable Gray Map
PNG	Portable Network Graphics
PPM	Portable Pixel Map

QoS	Quality of Service
RDDAI	Real-time Dynamic Display and Analysis of Insurgency
RFID	Radio Frequency Identification
RPF	Raster Product Format
SA	Situational Awareness
SDB	Spatial Database
SEDRIS	Synthetic Environment Data Representation and Interchange Spectrum
SIMNET	SIMulation NETwork
STAN	Surveillance and Target Acquisition Network
SUAV	Small Unmanned Aerial Vehicle
TDB	Terrain Database
TERN	Name of an UAV – a specific flown by Navy personnel Camp Roberts, California
TGA	Targa image file format
TIFF	Tagged-Image File Format
TOC	Tactical Operations Center
TNT	Tactical Network Topology
UAV	Unmanned Aerial Vehicle
USGS	U.S. Geological Survey
USIGS	United States Imagery and Geospatial System
UTM	Universal Transverse Mercator
UC	University of California
USSOCOM	United States Special Operations Command
VBTT	Vision Based Target Tracking
VPF	Vector Product Format
VRML	Virtual Reality Modeling Language
WPG	Word Perfect Format

## DEFINITION OF KEY TERMS

### **Base**

1: the “world” encompassed by an environment. Boundaries are specified to define the extent of the Base. 2: the root of an environment object hierarchy of objects with fixed positions in the world.

### **Component**

An object that is a part of an aggregator object. For example, vertex objects are components of their aggregator polygon. See aggregator.

### **Coordinate System**

An organized system for describing 2- or 3-dimensional locations.

### **Correlation**

A convergent relationship between parallel representations of the same data.

### **Datum**

A mathematical approximation to all or part of the earth's surface. Defining a datum requires the definition of an ellipsoid, its location and orientation, as well as the area for which the datum is valid.

### **Data Loss**

The loss of original information through multiple conversions or transformations of data.

### **Data Representation Model**

1: a description of the organization of data in a manner that reflects the information structure of an enterprise. 2: a description of the logical relationships between data elements. Each major data element with important or explicit relationships is captured to show its logical relationship to other data elements.

### **Data Representation**

A variety of forms used to describe the terrain surface itself, the features placed on the terrain, the dynamic objects with special 3- dimensional model attributes and characteristics, the atmospheric and oceanographic features, and many other forms of data.

### **Elevation**

The vertical component in a 3-dimensional measurement system. Elevation is measured in reference to a fixed datum.

**Face**

A region enclosed by an edge or set of edges. Faces are topologically linked to their surrounding edges, as well as to the other faces that surround them. Faces are always non-overlapping, exhausting the area of a plane.

**Feature**

1: a model of a real world entity. 2: a static element of the environment which exists but does not actively participate in environmental interactions.

**Fidelity**

1: the accuracy of the representation when compared to the real world. 2: (a) the similarity, both physical and functional, between the simulation and that which it simulates, (b) a measure of the realism of a simulation, or (c) the degree to which the representation within a simulation is similar to a real world object, feature, or condition in a measurable or perceivable manner.

**GeoKey**

In GeoTIFF, a GeoKey is equivalent in function to a TIFF tag, but uses a different storage mechanism.

**Geographic Coordinate System**

A Geographic CS consists of a well-defined ellipsoidal datum, a Prime Meridian, and an angular unit, allowing the assignment of a Latitude-Longitude (and optionally, geodetic height) vector to a location on earth.

**Geometry**

A very abstract class, encapsulating both the concepts of traditional geometry as well as other classes containing measured data, and organizational methods used to organize these traditional geometry and other “real” data classes within an environment.

**GeoTIFF**

A standard for storing georeference and geocoding information in a TIFF 6.0 compliant raster file.

**Grid**

A coordinate mesh upon which pixels are placed.

**Inheritance**

An object-oriented programming concept where a child class also has the features (attributes and methods) of its parent class. One of the types of relationships between objects in the data representation model.

**Interoperability**

1: enables distributed heterogeneous simulation systems to be interactive so that a meaningful exercise may be conducted. 2: the ability of a model or simulation to provide services to and accept services from other models and simulations, and to use the services so exchanged to enable them to operate effectively together. 3: two training systems interoperating to present a single training exercise in the same simulated space to a geographically dispersed audience.

**Library**

A complete list of unique item(s) of a certain type (whatever type the library contains) which can be referenced within the environment.

**Live Simulation**

A simulation involving real personnel operating real systems.

**Location 3-D Vertex**

A coordinate in 3-dimensional space.

**Meridian**

Arc of constant longitude, passing through the poles.

**Model**

A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process.

**Model Space**

A flat geometrical space used to model a portion of the earth.

**Natural Environment**

An earth-based environment modeled by an environment.

**Node**

A zero-dimensional primitive used to store a significant location.

**Original Data**

The source data utilized by a resource provider to construct their initial environmental representation.

**Parallel**

Lines of constant latitude, parallel to the equator.

**Pixel**

A dimensionless point-measurement, stored in a raster file.

**Polygon**

Thematically homogenous areas composed of one or more faces.

**Projected Coordinate System (PCS)**

An instantiation of a coordinate transformation. A planar, right-handed cartesian coordinate set which, for a specific map projection, has a single and unambiguous transformation to a geodetic coordinate system.

**Property**

A characteristic of an object.

**Projected Coordinate System**

The result of the application of a projection transformation of a geographic coordinate system.

**Raster Space**

A continuous planar space in which pixel values are visually realized.

**Rational**

In TIFF format, a Rational value is a fractional value represented by the ratio of two unsigned 4-byte integers.

**Resolution**

The degree of detail and precision used in the representation of real-world aspects in a model or simulation. Granularity.

**SDTS**

The USGS Spatial Data Transmission Standard.

**Scalability**

The ability of a distributed simulation to maintain time and spatial consistency, as the number of entities and accompanying interactions increase.

**SEDRIS**

An infrastructure technology that enables information technology applications to express, understand, share, and reuse environmental data.

**Terrain Representation**

The depiction of the terrain environment, which includes data on the location and characteristics of the configuration and composition of the surface of the earth, including its relief, natural features, permanent or semi-permanent man-made features, and related processes. It includes seasonal and diurnal variation, such as grasses and snow, foliage coverage, tree type, and shadow.

**Tag**

In TIFF format, a tag is packet of numerical or ASCII values, which have a numerical “Tag” ID indicating the information content.

**Textures**

Application of surface detail to a polygon by mapping an image to the polygon (i.e., to show foliage on a polygon to represent a tree).

**Tile**

A spatial partition of a coverage that shares the same set of feature classes with the same definitions as the coverage.

**Topology**

Any relationship between connected geometric primitives that is not altered by continuous transformation.

**Tagged Image File Format (TIFF)**

A platform-independent, extensive specification for storing raster data and ancillary information in a single file.

**Universal Transverse Mercator (UTM)**

An ellipsoidal transverse mercator projection to which specific parameters, such as central meridians, have been applied. The earth, between latitudes 84.0 degrees north and 80.0 degrees south, is divided into 60 zones, each generally 6 degrees wide in longitude.

**Virtual Simulation**

A simulation involving real personnel operating simulated systems.

## **ACKNOWLEDGMENTS**

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Last but not least, I want to thank my family for their concern and understanding during this time. Due to their care and support, I managed to accomplish these courses and achieve one of the most difficult goals of my life.

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# **I. INTRODUCTION**

## **A. THESIS STATEMENT**

The purpose of this thesis is to conduct the research necessary to develop integrated 3D terrain maps capable of supporting an Unmanned Aerial Vehicle (UAV) Flight and Mission Control Support System (FMCSS). In this work, the author explores the feasibility of exploiting digital topographic maps and further understanding of the digital terrain support available to UAV FMCSS developers. A thesis requirement is to assess adaptability and interoperability of available terrain maps and format conversion tools to improve an UAV FMCSS. Some of the challenges currently faced by researchers of an UAV FMCSS are discussed and possible solutions to the problems presented. The thesis explores and provides integration methodologies for the 2D map data required to implement the UAV experiments. Lastly, the field experiments conducted to demonstrate map data in live UAV target mensuration exercises are described.

## **B. MOTIVATION**

The U.S. military has determined that UAVs can provide a real and inexpensive approach for a new war strategy. UAVs are expected to offer progress in a variety of military areas, such as tactical surveillance, intelligence, high risk aerial missions, and target designation. In the future, teams of autonomous intelligent vehicles with common mission objectives will be integrated into military force structures<sup>1</sup>. A central motivation of this thesis is to develop an UAV FMCSS containing digital terrain data capable of supporting autonomous aerial vehicle missions.

UAV systems in the U.S. armed forces can already be linked with several computer-based applications used both in integrated missions and stand alone applications. One such application is the Perspective View Nascent Technologies (PVNT). PVNT was originally designed for tactical weapon tests and provides 3D

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<sup>1</sup> Mark Tanner, Creating Digital Environment for Multi-Agent Simulation, Master's Thesis, Naval Postgraduate School, December 2003.

battlefield simulation and UAV target locating functions. The PVNT addresses data generation and data utilization issues involved in creating high-fidelity real time databases.

The PVNT-based high-resolution 3D battlefield simulation will be augmented with 2D maps. By adding map data into the PVNT architecture, an integrated UAV flight and mission control support system can be built. This system will then be coupled to the NPS UAV being built by a team headed by Professor Isaac Kaminer at NPS. This team operates and tests the NPS UAV approximately four times per year at Camp Roberts (C.R.), California. The NPS UAV will provide sensor, communication, position telemetry, and flight control. The map and 3D perspective view capability will be integrated with the flying UAV in order to provide flight control, target location, and high precision tracking functions. This project will lead to a 3D flight and mission support system integrated with a flying NPS UAV operating (in prototype) an experimental target tracking demonstration.

### **C. GOALS**

The specific goal of this thesis is to determine if 2D map data can be integrated into a 3D battlefield visualization system in order to provide combined UAV flight, mission control, support, and training services. Issues include availability of shared situational awareness; displays; the ability to identify, track, and present enemy personnel and equipment in standard representations; and the ability to transfer such data to collaborative decision aids and visualization tools to effectively conduct highly-coordinated, combined U.S. and coalition activities better.

The specific test case to be supported involves the use of the Perspective View Nascent Technologies (PVNT) battlefield replicator to perform real time target location and tracking. In order to execute such missions with relatively low-cost optical sensors, techniques involving registration and feature matching between measured and simulated images can be employed. Measurement and analysis of tactical battlefield features requires the generation of metrically accurate terrain elevation and surface reflecting databases at one-meter resolution. Standard 90 and 30 meter (DTED level I and II) data available from the National Geospatial-Intelligence Agency (NGA) are augmented by a

PVNT high-resolution database creation software to process aerial images into one-meter data sets. PVNT one-meter databases are now available for U.S. locations including Fort Hunter Liggett, California, and Camp Roberts, California. The ability of the PVNT system to locate and track both targets and UAVs, their sensor ground prints, and communication antenna patterns has been demonstrated.

Currently, the results of such calculations can only be displayed on the image maps derived directly from the PVNT terrain database. In order to make PVNT terrain-based calculations more useful and interoperable with other tactical decision aids, it is necessary to generate and display 3D targeting, flight and sensor coverage information on conventional 2D military maps.

The central goals of this thesis are to 1) determine the availability of such 2D terrain map products, 2) determine the availability of tools to convert such maps into formats compatible with a PVNT insert function, and 3) assess the effectiveness of the 2D terrain maps to display 3D target, sensor and sensor footprint data for the tactical commander.

The last goal of this thesis is to provide a methodology for the acquisition, transfer, and insertion of 2D digital terrain maps in new and unexpected areas of the world where UAV services may be required.

The author envisions this methodology to be the first step in the design of a FMCSS capable of quickly generating open source digital topographic maps with the PVNT operational system and manually layering real world digital terrain data on PVNTs. The author emphasizes this research by analyzing alternatives of the most commonly used digital terrain manipulation and visualization packages. The author will leverage current commercial-off-the-shelf (COTS) techniques in this effort. The author's long-term vision is to be able to find, convert, and merge 2D maps into a complete high-fidelity integrated system.

In summary, this work will provide both a tool and a design methodology for an analyst to utilize high-fidelity terrain data sets. It will function as a "how to" manual to help analysts understand which information and tools are available to use for different

types of projects. This work will directly contribute to the further development of high-resolution terrain generation for simulation analysis and the integration of real terrain into ongoing agent-based MOVES simulation research.

#### **D. ORGANIZATION**

This thesis consists of eight chapters that cover various aspects of the research process, including data collection, data representation, research methods, and the final research experiment.

**Chapter I: Introduction.** Identifies the purpose and motivation of this research. Establishes the goals, gives a general outline of the work, and defines the problem the author is trying to solve. Key strategies for implementing the central part of the thesis are discussed and suggestions for how to implement the research are provided.

**Chapter II: Background.** This chapter discusses basic digital topography concepts, describes the basic elements of ground combat simulation as well as previous research in the field of metrically accurate real-time battlefield modeling and simulation. The chapter includes a discussion of the source of the concepts and how these basic concepts relate to the research. Information on several formats used by the UAV FMCSS is presented. Mainstream data representations and formats available to the military and civilian developer are detailed.

**Chapter III: Requirements.** This chapter states the requirements determined for the UAV flight and mission control system. It describes the necessary characteristics, formats, and data criteria represented in this work.

**Chapter IV: Data Representations.** This chapter can also be called the special format data search chapter. It provides information on how a user can quickly gather the data in the necessary formats.

**Chapter V: Data Preparation System.** This chapter describes the making of the virtual environment, the architecture of the system, and the applications used in its development. The chapter shows a real user how to use the data and the necessary conversion tools effectively, and how to use these tools to obtain final data, and import that data into the PVNT system.

**Chapter VI: Test and Experimentation.** This chapter describes the experimental set-up used to validate the use of the 3D maps for the UAV flight and mission control system. This chapter indicates to the user or operator what was done in experiments conducted at Camp Roberts, as well as connected experiments with the NPS Giga Lab and Camp Roberts.

**Chapter VII: Results.** This chapter presents the results of the experiment. A table of successful and unsuccessful results of the experiment is provided.

**Chapter VIII: Conclusions.** This chapter describes the conclusions drawn from the results of the proof of concept study, along with some discussion on the research and how to improve it.

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## **II. BACKGROUND**

### **A. INTRODUCTION**

This chapter discusses basic digital topography concepts, the source of the concepts in general or basic terms and how this basic concept relates to the research. It illustrates several formats being used by the UAV FMCSS. It describes the mainstream data representations and formats available to the military and civilian developer.

### **B. MILITARY MAPS CHARACTERISTICS**

Officers must know how to use and read a map. To obtain a basic understanding of this research paper, it is first necessary to understand the features of the metrically accurate terrain-elevation databases which will be used for an UAV FMCSS, and second, it is essential to know where to find this sort of data. Data collection and development are paramount to applications in this research. Data development for a UAV FMCSS must be customized to the requirements of the UAV FMCSS, to be within the boundaries of the study area, and be available mostly using open source information from the Internet. According to the National Geospatial-Intelligence Agency, military maps are categorized by scale and type.<sup>2</sup>

#### **1. Scale**

Since a map is a graphic representation of a portion of the earth's surface drawn to scale as seen from above, it is important to know which mathematical scale has been used.

##### ***a. Small***

Those maps with scales of 1:1,000,000 and smaller are used for general planning and for strategic studies. This map covers a very large land area at the expense of detail.

##### ***b. Medium***

Those maps with scales between 1:1,000,000 and 1:75,000 are used for operational planning. They contain a moderate amount of detail, but terrain analysis is

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<sup>2</sup> Map Reading, Part 1, retrieved July 24, 2005 from <http://www.map-reading.com/ch3-3.php>.

best done with the large-scale maps described below. The standard medium-scale map is 1:250,000. Medium scale maps of 1:100,000 are also frequently encountered.

***c. Large***

Those maps with scales of 1:75,000 and larger are used for tactical, administrative, and logistical planning. These are the maps that a soldier or junior leader is most likely to encounter. The standard large-scale map is 1:50,000; however, many areas have been mapped at a scale of 1:25,000.

**2. Types**

***a. Planimetric Map***

This is a map that presents only the horizontal positions for the features represented. It is distinguished from a topographic map by the omission of relief, normally represented by contour lines. A planimetric map is sometimes called a line map.

***b. Topographic Map***

This is a map that portrays terrain features in a measurable way (usually through use of contour lines). The horizontal positions of the features represented are also portrayed. The vertical positions, or relief, are normally represented by contour lines on military topographic maps.

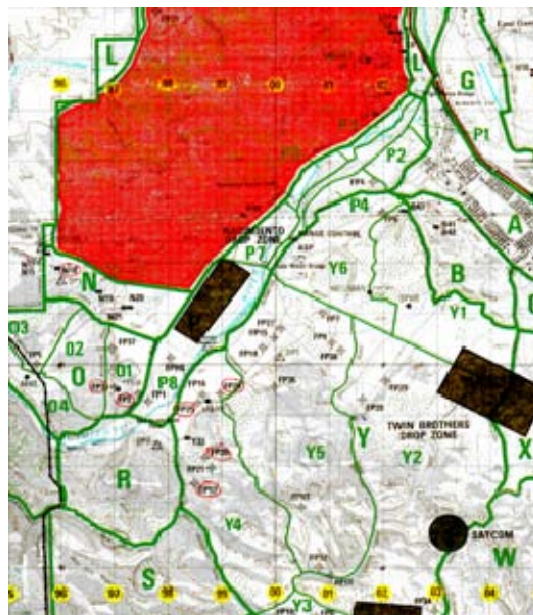


Figure 1. 1:50000 Scale Military Topographic Map.

*c. Photomap*

This is a reproduction of an aerial photograph upon which grid lines, marginal data, place names, route numbers, important elevations, boundaries, and approximate scale and direction have been added.

*d. Joint Operations Graphics*

These maps are based on the format of standard 1:250,000 medium-scale military topographic maps, but they contain additional information needed in joint air-ground operations. The map of choice for land navigators is the 1:50,000-scale military topographic map.

The purpose of a map is to permit one to visualize an area of the earth's surface with pertinent features properly positioned. The map's legend contains the symbols most commonly used in a particular series or on that specific topographic map sheet. Therefore, the legend should be referred to each time a new map is used.

Ideally, all the features within an area would appear on a map in their true proportion, position, and shape. This, however, is not practical because many of the features would be unimportant and others would be unrecognizable because of the reduction in size.

The mapmaker has been forced to use symbols to represent natural and man-made features of the earth's surface. These symbols resemble, as closely as possible, the actual features themselves as viewed from above. They are positioned in such a manner that the center of the symbol remains in its true location.<sup>3</sup>

The PVNT system uses 1:50,000-scale maps or higher resolution. Since tactical analysis is done at the 1:50,000 and larger scales, this provides the commander with detailed information of a specific areas-of-interest on the battlefield.

**C. UAV MISSION SUPPORT MAPS**

Don Shipley, representative of the Defense Advanced Research Projects Agency (DARPA) Grand Challenge, has said that by 2015, the goal is for one-third of all fighting

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<sup>3</sup> Map Reading, Part 1, retrieved July 24, 2005 from <http://www.map-reading.com/ch3-3.php2>.

vehicles of the American military complex to be unmanned fighting vehicles. Hence, it is suggested that fighting systems must have an integrated mission control system that may connect to the digital terrain spatial database.

In order to enhance a soldier's effectiveness on the battlefield, simulation systems depicting operational scenarios require the accurate calculation of concealment, cover, and detection parameters. Measurement and analysis of tactical battlefield features require the generation of metrically accurate terrain-elevation databases at higher resolution than the standard 90- and 30-meter data available from the National Imagery and Mapping Agency (NIMA). However, the generation and exploitation of higher-resolution terrain data can be slow and expensive, and potentially, a significant obstacle in conducting tactical terrain analysis.<sup>4</sup>

Military operational planning depends on having a reliable and accurate understanding of the terrain. This includes detailed modeling of elevation, slope, and aspect, as well as the minute features contained therein. The military uses Digital Terrain Models (DTMs) for visualization, inter-visibility analysis, virtual displays, and line of sight analysis.

A major challenge in the civilian and Department of Defense (DoD) simulation community is the definition of a common environmental format. This includes activities like interoperability, data interchange, common formats and common data representations. There are numerous activities and organizations in DoD addressing these problems. The Synthetic Environment Data Representation and Interchange Specification (SEDRIS) of the Defense Advanced Research Projects Agency (DARPA) and U.S. Army Simulation, and the TRaining, and Instrumentation COMmand (STRICOM), now the Program Executive Office for Simulation, TRaining, and Instrumentation (PEO-STRI) program are among them. Mainly, the SEDRIS projects deal with environmental data. Environmental data is an integral part of many of today's information technology applications. The use of environmental data will grow substantially as availability and access to such data increases, and as tools for the manipulation of environmental data

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<sup>4</sup> Dr. Wolfgang Baer, The PVNT Documentation, Naval Postgraduate School, 2004.

become less expensive and more sophisticated. SEDRIS is fundamentally about: (a) the representation of environmental data, and (b) the interchange of environmental data sets. To achieve the first, SEDRIS offers a data representation model, augmented with its environmental data coding specification and spatial reference model, so that one can articulate one's environmental data clearly, while also using the same representation model to understand others' data unambiguously. Therefore, the data representation aspect of SEDRIS is about capturing and communicating meaning and semantics.<sup>5</sup>

#### **D. MILITARY MAP SUBSTITUTES**

Military maps are often not available, and it will be necessary to use substitute maps. The substitute maps can range from foreign military or commercial maps to field sketches. To access such maps, open source information-gathering methods that are useful for both military and researchers are necessary. The following sections discuss these methods.

##### **1. Foreign Maps**

These are maps that have been compiled by nations other than our own. When these must be used, the marginal information and grids are changed to conform to U.S. standards if time permits. The scales may differ from U.S. maps, but they do express the ratio of map-distance to ground-distance and can be used in the same way. The legend must be used since the map symbols almost always differ from U.S. symbols. Since the accuracy of foreign maps varies considerably, they are usually evaluated in regard to established accuracy standards before they are issued to U.S. troops.

##### **2. Atlases**

These are collections of maps of regions, countries, continents, or the world. Such maps are accurate only to a degree and can be used for general information only.

##### **3. Geographic Maps**

These maps give an overall idea of the mapped area in relation to climate, population, relief, vegetation, and hydrography. They also show general location of major urban areas.

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<sup>5</sup> SEDRIS: What It Is and Is Not, retrieved December 28, 2005 from [http://www.sedris.org/abt\\_trpl.htm](http://www.sedris.org/abt_trpl.htm).

#### **4. Tourist Road Maps**

These are maps of a region in which the main means of transportation and areas of interest are shown. Some of these maps show secondary networks of roads, historic sites, museums, and beaches in detail. They may contain road and time distance between points. Careful consideration should be exercised about scale when using these maps.

#### **5. City/Utility Maps**

These are maps of urban areas showing streets, water ducts, electricity and telephone lines, and sewers.

#### **6. Field Sketches**

These are preliminary drawings of an area or piece of terrain.

#### **7. Aerial Photographs**

These can be used as map supplements or substitutes to help with terrain analysis, route planning, or to guide movement.<sup>6</sup>

#### **8. Google Earth Maps**

Google Earth streams the world over wired and wireless networks enabling users to go virtually anywhere on the planet and see places in photographic detail. This is not like any map ever seen before. This is a 3D model of the real world, based on real satellite images combined with maps, guides to restaurants, hotels, entertainment, businesses and more. It is possible to zoom from space to street level instantly and then pan or jump from place to place, city to city, and even country to country.<sup>7</sup>

#### **9. ArcGIS Maps**

ArcGIS is an integrated collection of Geographic Information System (GIS) software products for building a complete GIS for an organization. The ArcGIS framework makes it possible to deploy GIS functionality and business logic wherever it

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<sup>6</sup> Map Reading, Part 1, retrieved July 24, 2005 from <http://www.map-reading.com/ch3-3.php>.

<sup>7</sup> NJROTC General Information Page, retrieved December 30, 2005 from <http://www.njrotc.org/main/Pages/phpGeneralinfo.htm>.

is needed—in desktops, servers (including the Web), or mobile devices. This architecture, coupled with the geodatabase, provides the tools to assemble intelligent geographic information systems.<sup>8</sup>

#### **E. JUSTIFICATION FOR OPEN SOURCE METHODOLOGY**

This thesis concentrates on the use of open source data generally available on the Internet. The development of a global network Internet has grown rapidly. This growth is the result of constantly evolving hardware capabilities and the need for diversified information on extensive subjects. The presence of huge amounts of information accessible through a network also makes the Internet attractive as a source of map data. It is necessary to note that the structure of data presentation is still insufficient for unequivocal localization of the necessary information. Rapid development of increased bandwidth due to the addition of new servers and connections and richer, semantic content through standardized mark-up languages will allow the Internet to provide full-function methods for search and filtrations of maps in the near future.

Therefore, the majority of modern companies working in the sphere of information technology are developing programs and new technologies that focus on use within the limits of the Internet/Intranet. Monetary and intellectual investments in the World Wide Web (WWW) have been and continue to be large. This will allow further development of the Internet for storage and information, and also for complex multilevel systems and data analysis. The expectation, therefore, is that Internet retrieval of open source data will increase utility and applicability. Hence, methods are being developed for the retrieval of required information from the Internet.

#### **F. PERSPECTIVE VIEW NASCENT TECHNOLOGIES (PVNT)**

The PVNT system, developed by Dr. Wolfgang Baer of the Naval Postgraduate School (NPS) in Monterey, California, greatly enhances the cost effectiveness of high-resolution terrain data by employing low-cost personal computer (PC)-based software. The software can generate the terrain data and use it to create perspective views and to perform line-of-sight (LOS) and weapons-effectiveness analysis.

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<sup>8</sup> ESRI – GIS and Mapping Software, retrieved January 1, 2006 from <http://www.esri.com/software/arcgis/index.html>.

Several years ago, the investigation of porting costs, performance, and platform cost analysis showed that both the cost and maintenance of future systems will greatly benefit from the utilization of low-cost PC hardware and standard software. A combination of NPS student and research efforts has now successfully ported the perspective view generation and line-of-sight software to a PC platform. The availability of high speed, low-cost PC-based workstations to host the software has greatly enhanced the cost effectiveness of 1-meter and higher resolution terrain databases.

#### **G. CAMP ROBERTS EXPERIMENTS**

The Tactical Network Topology (TNT) field experimentation program is a cooperative effort between the Naval Postgraduate School (NPS), the United States Special Operations Command (USSOCOM), and several government laboratories. NPS' participation has been made possible by Congressional funding from the Center for Defense Technology and Education for the Military Services (CDTEMS), and from USSOCOM and the Office of Force Transformation. Other companies and government organizations have provided various components for evaluation within the field experiments. Navy Fleet Composite Squadron Six (VC-6) has participated in all Surveillance and Target Acquisition Network (STAN)/TNT experiments, providing TERN UAV flight support. TNT is a continuation of the STAN program, which has transitioned into other USSOCOM funded programs.

#### **H. SUMMARY**

This chapter discussed basic digital topography concepts in general and how these specifically relate to the research. Also illustrated were several formats available to the military and civilian developer. The section on Military Maps Characteristics described National Geospatial-Intelligence Agency military maps by scale and type. The section on UAV Mission Support Maps characterized the necessity of digital terrain spatial databases for an integrated mission system. The section on Military Map Substitutes provides methods for using military map substitutes. The section on Justification of Open Source Methodology described the Internet as one of the main sources of map data. In the section on Perspective View Nascent Technologies, the main features of PVNT was described and the whole system was briefly characterized. The final section identified main government bodies involved in the Camp Roberts experiments.

### **III. REQUIREMENTS**

#### **A. INTRODUCTION**

The U.S. military has determined that UAVs can provide a real and inexpensive approach for new war strategy. In the past, the military used to apply an old military strategy, especially with respect to the deployment of forces and weapons to the battlefield. As stated by Gen. Ronald R. Fogleman, the U.S. Air Force Chief of Staff:

This strategy focused on destroying enemy forces in the field as the surest way to victory. It relied on the creation of large masses of forces that would employ mass, concentration and firepower to attrite enemy forces and defeat them in generally successful, but many times costly, battles.<sup>9</sup>

New war strategies are emerging based upon information identity and computer technologies. One component of the new strategy is the UAV. In fact, UAVs can implement fast, complete operations with minimum casualties. For example, in the recent wars with Afghanistan and Iraq, the U.S. military used different types of UAVs, to implement many different kinds of operations.

#### **B. UAV USAGE**

The past two decades have witnessed a remarkable increase in the utilization of UAVs by armed forces, both in the U.S. and abroad. While large UAV systems have already proven their utility, small UAVs have just started to emerge. Recent advances in microelectronics and solid-state micro-machined devices have resulted in miniature, low-cost sensors, actuators and microcomputers available at reasonable prices. These advances have made it possible to implement capabilities on small UAVs, which were previously only possible on larger UAVs. Vision-Based Target Tracking (VBTT) is one such capability which could result in significant improvements in time on target, the ability to conduct detailed reconnaissance, and the ability fuse data from many sensors.

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<sup>9</sup> Gen. Ronald R. Fogleman, retrieved February 11, 2004 from [http://www.af.mil/news/techinnovations/2003-11-17-dronefilght\\_x.html](http://www.af.mil/news/techinnovations/2003-11-17-dronefilght_x.html).

## **C. UAV CONTROL SYSTEM DESCRIPTION**

### **1. Conceptual Characteristics of UAVs**

This chapter states the requirements determined for the UAV flight and mission control system. This chapter presents the conceptual characteristics of an UAV FMCSS. The UAV Flight and Mission Control Support System integrates digital map sources and flight control functions into an UAV rapid targeting system in order to provide improved control capabilities for the TELEMASTER UAV under construction at NPS.

### **2. Control System**

According to the TNT-05-03 Project Report implemented by a group of research professors and students from NPS, a UAV system was developed with the following components and capabilities.

The VBTT system (Figure 2) includes a Senior Telemaster UAV modified to carry a two-axis gimbaled camera that acquires video and sends the information to the Automated Target Tracking (ATT) computer in real time. During a mission, the operator of the ATT computer may identify the target of interest. The target appears inside a small, rectangular polygon and is tracked by engaging the track mode. The position of the target in a camera frame is identified by the Cartesian coordinates of its centroid. This information is processed by the control algorithm (NPS ground station) that sends guidance commands to the UAV and controls the gimbaled camera to keep the target in the center of the video frame.<sup>10</sup>

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<sup>10</sup> Dr. Vladimir Dobrokhodov, Dr. Kevin D. Jones, Dr. Isaac I. Kaminer, TNT-05-03 Project Report, Monterey, California, 2005 (received by mail July 25, 2005).

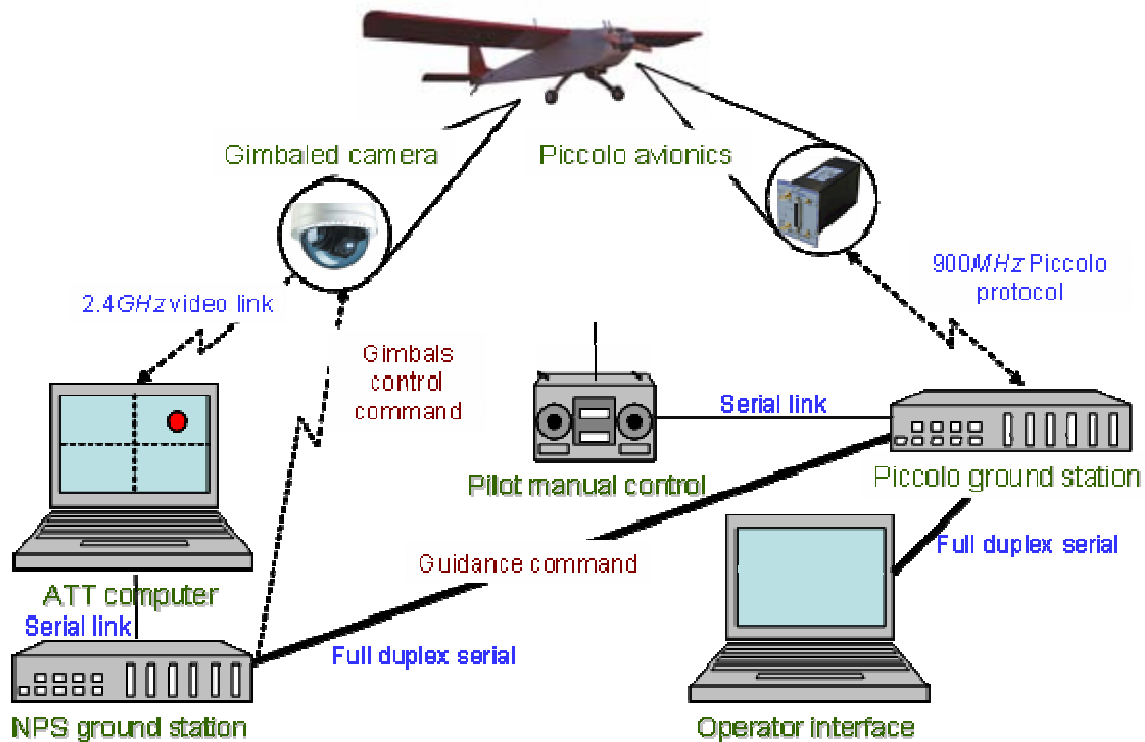


Figure 2. VBTT Architecture.

Three major components were developed and integrated into one system. The first component included a vision-based target tracking capability that used imagery provided by a gimbaled camera. Development of this component involved the design of a miniaturized gimbaled camera and controller, and integration of the ATT software by PerceptiVU, Inc. Automated Motion Tracking (AMT) software enables one to track an object in motion with a gimbaled camera (Pan-Tilt) as it moves within a fixed camera scene. AMT employs the Matrox Meteor II frame grabber installed into a high-performance computer. Principal features of the AMT software include:

- Capture from standard analog video sources (NTSC, RS170)
- Wingman Extreme digital 3D Joystick Controller
- Three tracking algorithms
  1. Dynamic centroid
  2. Hottest spot thresholding
  3. Dynamic correlation

- Three polarity options
  1. White hot
  2. Black hot
  3. Auto polarity
- Six fixed-target size and a custom size
  1. Custom size
  2. Very small target
  3. Small target
  4. Medium target
  5. Big target
  6. Very big target
- Interactive tracking gain
- Allows for data logging in ASCII file

Performance of the ATT system (fragmentation rate and resolution) depends on the overall capability of the host computer. The current setup allows stable video sampling at 30 Hz and is based on the following principal components:

- Pentium IV – 3.2 GHz processor with 800 MHz front side bus
- 250 GB hard drive with 7200 rpm
- 1 GB RAM

The second component of the system includes the integrated UAV/camera control system. It contains several task-specific inner-loops for the UAV guidance, navigation and control (GNC), as well as for steering the gimbaled camera (Figure 3).

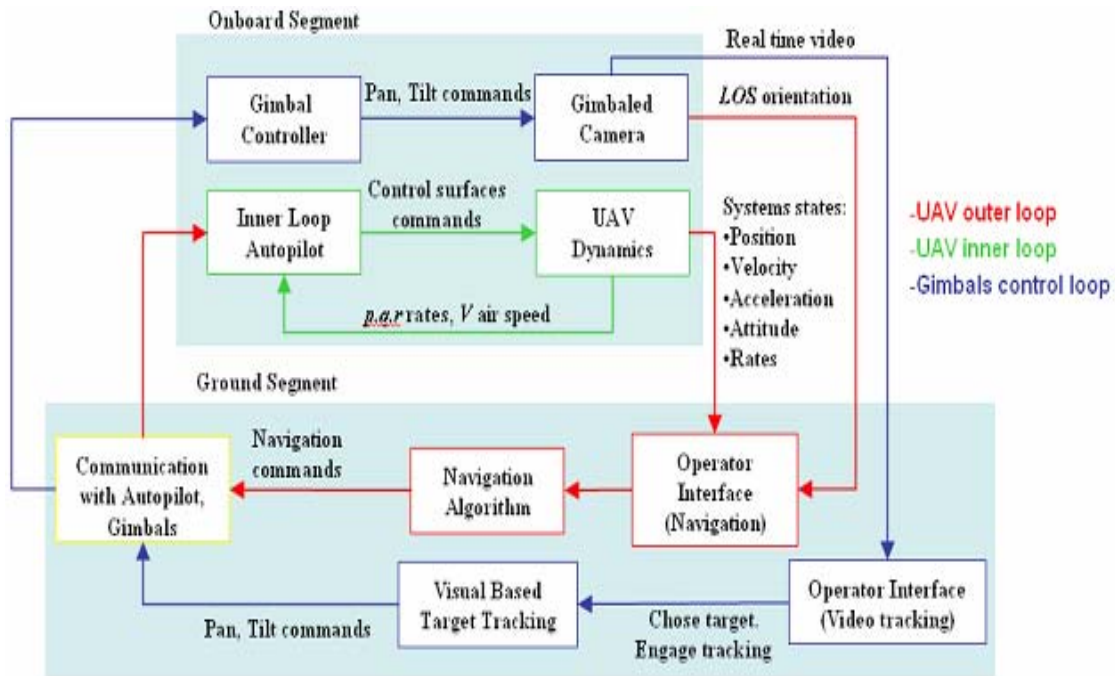


Figure 3. Control System Architecture.

The GNC algorithm (Figure 4) was designed to solve two principal tasks. First, it has to guide (“Guidance”) the UAV around the target while keeping the target in the camera frame.

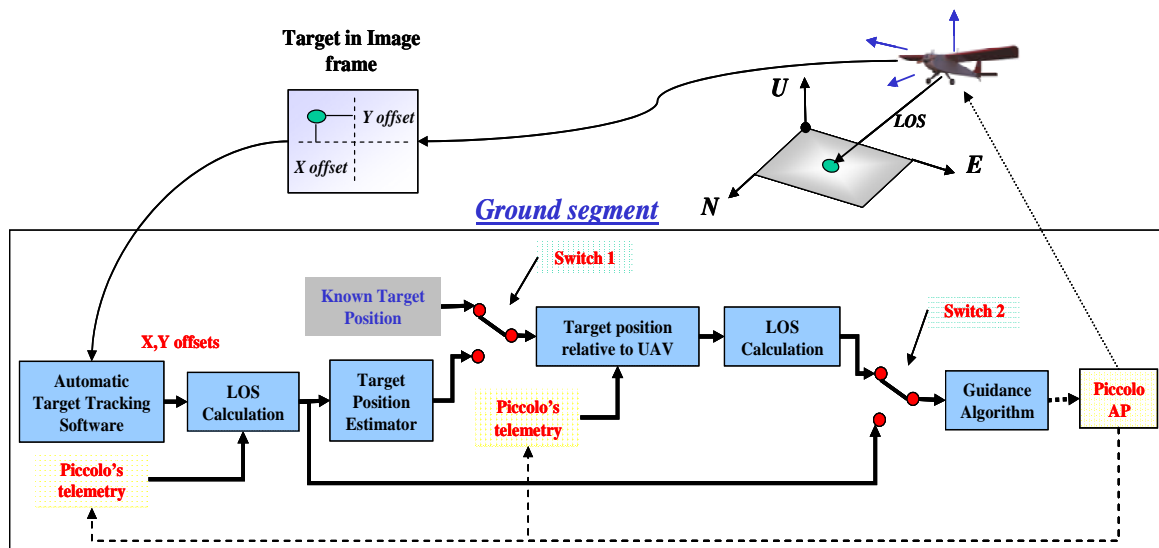


Figure 4. Control and Guidance Architecture.

Second, it has to reduce the range estimation errors (“Target Position Estimation”), because the accuracy of the range estimation depends on the translating motion of the camera. The estimation error is minimized when the target moves parallel to the camera image plane.

The third component consists of two filters for target position estimation (Figure 4). These filters include the Polar Coordinate (PC)-based estimator and the Cartesian coordinate (CC)-based estimator. The PC filter is a nonlinear constant-gain Kalman filter for the LOS angular rate and the range estimation. Design of the CC filter is cast in the framework of Linear Parameter Varying Systems.<sup>11</sup>

### **3. Hardware**

A customized Senior Telemaster model aircraft is used to house the gimbaled camera, wireless video, and serial links, as well as the Piccolo autopilot with its dedicated control link. The modified Senior Telemaster UAV shown in Figure 5, with a 2.5 m wingspan and 8 kg weight, is heavily modified to suit this research’s needs, including a reinforced two-piece bolt-on wing with barn-door ailerons, removable tail surfaces, and a much larger fuselage to house payload components. It is powered by a 23 cm<sup>3</sup> two-stroke gasoline engine, and with a 1500 cm<sup>3</sup> gas tank, the plane has an endurance of about three hours. The UAV uses the Piccolo autopilot. Its primary payload is a gimbaled camera, mounted just under the nose (Figure 6). The custom pan-tilt unit is driven by COTS hobby servos, controlled from the ground via a 900 MHz serial modem, and provides 360° of pan and 90° of tilt. The gimbal currently has a high resolution, low-light, black and white camera, but it is designed to accept two cameras at a time: eventually, either a color camera or an IR camera will be added. Video is transmitted to the ground using an 800 mW 2.4 GHz link from Electra Enterprises, with either an omni antenna for a few kilometer range or a high-gain tracking patch for up to 15 kilometer range.

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<sup>11</sup> Dr. Vladimir Dobrokhodov, Dr. Kevin D. Jones, Dr. Isaac I. Kaminer, TNT-05-03 Project Report, Monterey, California, 2005 (received by mail July 25, 2005).



Figure 5. Modified Senior Telemaster UAV.



Figure 6. Gimbal Detail in the Telemaster.

Figure 6 shows the pan-tilt gimbal under the nose, with a low-light high-resolution camera mounted on one side. Note the engine exhausts upward to keep the camera clean. A close-up of the equipment bay in Figure 7 shows the aft fuselage, revealing slide-in cards with the video transmitter, a serial-to-PWM card to drive the gimbal servos, Freewave radio to receive the serial commands for the gimbal from the ground, and the power conversion for the servos.



Figure 7. Electronics Bay in the Telemaster.

The electronics components are mounted to lightweight aircraft-plywood trays, which slide into EPT foam blocks, allowing for vibration isolation and easy access to all of the components. A Hyde softmount is used to isolate engine vibration from the airframe, increasing both video quality and the lifespan of the avionics. At idle, the vibration is still quite noticeable in the video, but above about 10% throttle, the vibration is almost completely damped, providing very clean video.

#### 4. Mission Control System with PVNT

Previous work at NPS has included the development of a vision-based target tracking and estimation system for stationary targets. The flight test setup and target tracking workstation is shown in Figure 8 with the small UAV.

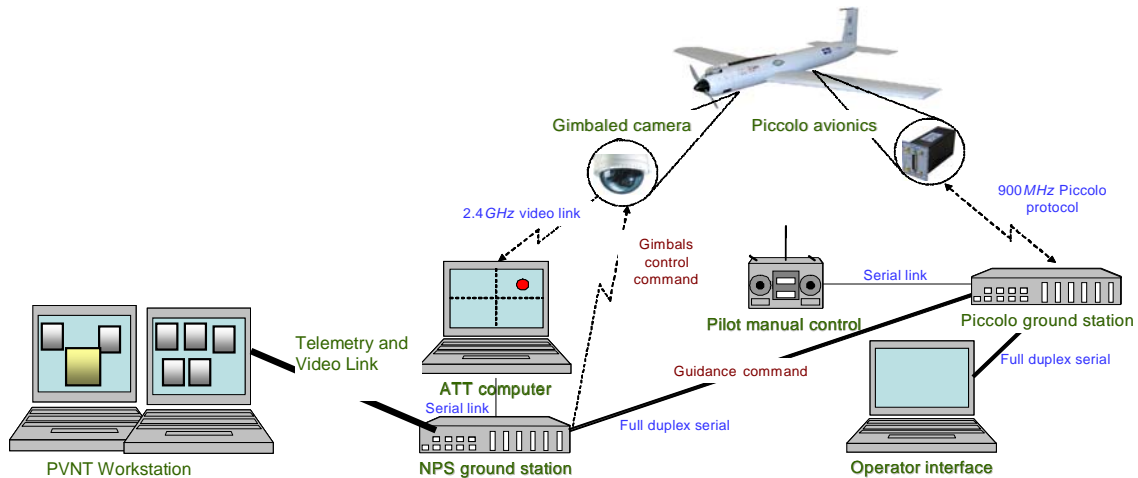


Figure 8. Flight Test Setup and PVNT Workstation.

The video stream obtained by the onboard camera is broadcast on a 2.4 GHz link and processed on the ground by OTS PerceptiVU image processing software.<sup>12</sup> PerceptiVU allows a user to select and lock on a target displayed on a ground station screen. In the configuration used in this task, PerceptiVU provides coordinates of the centroid of the target selected by the user. These are then employed by the control and filtering algorithms developed at NPS and implemented on the NPS ground station.<sup>13</sup> Recent flight tests of the system show 20-30 m accuracy in target geo-location obtained with 15-20 seconds of tracking. In addition to the real-time tracking and estimation algorithms employed by the ground station, the UAV's telemetry and onboard image are shared over a network and sent to the PVNT vision-based target tracking system.

<sup>12</sup> PerceptiVU Inc., retrieved October 12, 2005 from [www.Perceptive.com](http://www.Perceptive.com).

<sup>13</sup> Ick H. Whang, Vladimir N. Dobrokhodov, Isaac I. Kaminer, and Kevin D. Jones, "On Vision-Based Target Tracking and Range Estimation for Small UAVs," AIAA 2005-6401, AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15 – 18, 2005, San Francisco, California.

The vision-based target tracking system consists of two computers. One executes the CR\_interface (Camp Roberts\_interface) program that captures and displays six seconds of images (each at one-second intervals) and synchronized with telemetry messages. A second computer running the PVNT software generates telemetry-controlled calculated perspective views from received GPS and camera angle coordinates at one-second intervals. The PVNT is a general software package addressing the generation and utilization of metrically accurate 1-meter terrain databases for measurement, analysis, and visualization of live/virtual tactical battlefield situations. In this application, the calculated and measured views are registered and differenced to highlight the target.<sup>14</sup>

Several mouse controls and image differencing algorithms are available to help this process. When the calculated and measured view are close enough to perform target location, the PVNT operator then performs a final target location by clicking on the location in the calculated image where the target would appear if it were in the database. The advantage of this vision-based target tracking approach is that the accuracies of target location are determined almost exclusively by the accuracy of the database and do not require precision gimbals or accurate UAV location data.<sup>15</sup>

The combined system provides target position estimates with 1-2m accuracy and has been successfully demonstrated in several recent TNT experiments conducted by NPS at Camp Roberts.

#### **D. DATA REQUIRED TO SUPPORT UAV FMCSS**

Traditionally, in the military environment there is a presentation of a 2D map that shows the so-called *battle space* in situational awareness (SA) displays. SA displays typically provide geospatial information, along with troop units, routes, assets, and planning objects. UAV missions are defined and managed with the traditional two-dimensional SA displays. In contrast, the PVNT addresses data generation and data

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<sup>14</sup> W. Baer and Todd Campbell, "Target Location and Sensor Fusion through Calculated and Measured Image Differencing," Signal Processing, Sensor Fusion, and Target Recognition XII, Ivan Kadar (Ed.), *Proceedings of SPIE*, Vol. 5096 (2003), p. 169.

<sup>15</sup> I. Kaminer, V. Dobrokhodov, K. Jones and W. Baer, "Vision Based Target Tracking and Network Control for Mini UAVs," Proposal submitted to Mr. J. Buss, Office of Naval Research (received by mail October 13, 2005).

utilization issues involved in creating high-fidelity, three-dimensional real-time databases. The PVNT provides support for producing metrically accurate representations of the battle space. It is designed to operate in an environment where live and virtual worlds come together. This system provides the capability to generate 1-meter fidelity terrain databases and 1-cm target view databases for use in weapon substitution, command and control applications, and after action test review in force-on-force operational field tests. The PVNT has the ability to create higher fidelity databases.<sup>16</sup> The current PVNT system allows for the display of map layers as controlled within the *edit-dialog-show* command. However, the actual 2D map data along these that is capable of importing such data have not been available. This means UAV mission support functions, normally shown on traditional SA displays, could not be properly implemented.



Figure 9. Image-Based Map on SA Display in PVNT.

<sup>16</sup> <http://www.cs.nps.navy.mil/people/faculty/baer/pegasus.html>, retrieved August 6, 2005.

For example, Figure 9 shows an image-based map on SA display with two sensor ground prints. Such displays and the real-world 3D database behind them are necessary to perform actual calculations. However, such a display is much like looking at the real world. Features are recognized from their visual signatures and locations are known only because the operator is familiar with the terrain.

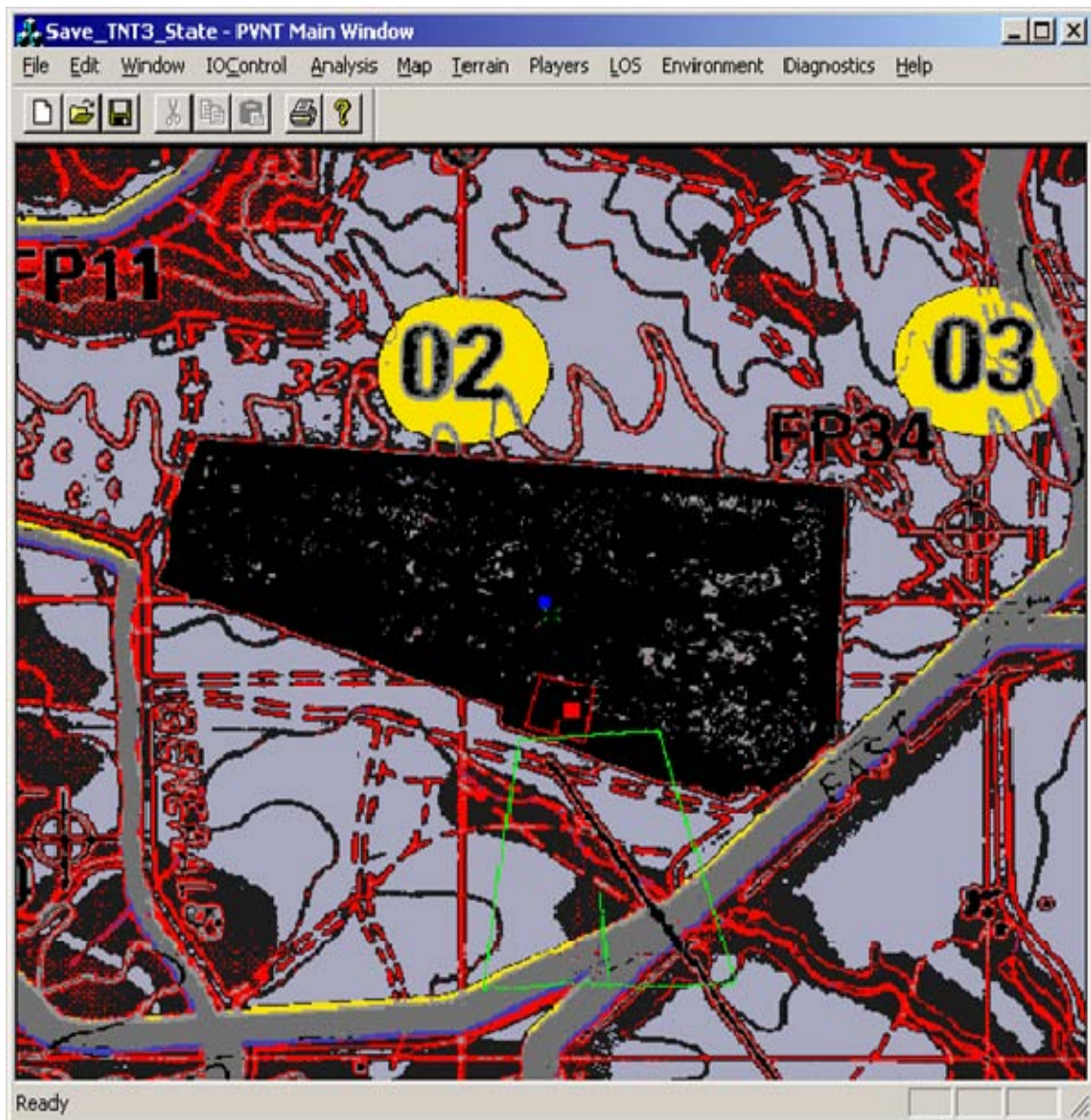


Figure 10. Military Topographic Map with Elevation Contours.

Figure 10 on the other hand shows a military topographic map with elevation contours and feature icons familiar to the soldier and used as the background for standard SA displays. In order to display the result of physical calculations in a format familiar to the soldier, it is necessary to present target, player locations, routes, and sensor ground printed on standard maps.

In order to successfully import source data, it is necessary to find data sources which either are in, or can be easily converted to, PVNT-compatible files. The current PVNT uses the standard Microsoft BitMap format. Standard and easily accessible tools are available to convert a variety of data sources to BitMaps. Combinations of source data and conversion tools employed are discussed in subsequent chapters. The purpose of this thesis work is to add the PVNT Topographic Map Layer in the Display Function Modifications. That new layer gives an operator the chance to supervise the battlefield, and to make a proper decision using traditional SA display maps. It also gives the operator a chance to compare position location derived from mathematical model data (“topographic map layer”), telemetric data, and GPS coordinates. The primary source of information used is derived from open source cartographic products (soft maps), such as vector maps, 2D raster images, aerial photographs, satellite imagery, toponymes, etc.

#### **E. SMALL UNMANNED AERIAL VEHICLE (SUAV) SPECIFICS**

The U.S. Army, Navy, Marine Corps, and Special Operations Forces have invested in the development of Small Unmanned Aerial Vehicles (SUAVs) to provide tactical imagery to small units (battalion and below) for reconnaissance, surveillance, target acquisition (RSTA), and battle damage assessment (BDA). Two U.S. Army UAV programs, the Hunter and the Shadow, have been deployed successfully in the Persian Gulf, Bosnia, Afghanistan, Iraq, and other conflict locations.<sup>17</sup>

The Army’s Future Combat System (FCS) initiative identifies a requirement for two classes of SUAVs

- Class I = Backpackable
- Class II = Vehicle/Man Transportable

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<sup>17</sup> DoD, 2002.

In 2003, the Army Strategic Planning Board designated the SUAV as an “Urgent Wartime Requirement.” The Board projected that SUAVs will be used in direct support of the Global War on Terrorism with immediate application to Army forces engaged in Operation Iraqi Freedom and Operation Enduring Freedom.<sup>18</sup>

UAV research, development, and acquisition programs in the DoD have been sporadic and haphazard over the years and, perhaps as a consequence, the current technologies suffer from high loss rates and require substantial manpower to operate and maintain. One analysis concluded that the U.S. has had a “three-decade-long history of poor outcomes in unmanned aerial vehicle development efforts.”<sup>19</sup> However, the U.S. is entering a new era in which the unbridled engineering innovation that has characterized UAV design and development is likely to give way to more systematic, systems engineering approaches.

This paragraph focuses on U.S. military SUAVs, as opposed to High Altitude Long Endurance HALE UAVs or Medium Altitude and Endurance (MAE) UAVs, such as the Global Hawk or the Predator. High altitude generally refers to above 50,000 feet and long endurance to 24 hours or more. By contrast, current SUAVs tend to operate at less than 5,000 feet and their endurance is on the order of several hours. Examples of current SUAVs are the Topographic Environment Research Network (TERN), Silver Fox, Swift, Pointer, Raven, and Dragon Eye. The Hunter and the Shadow, by contrast, are larger and are usually called “Tactical” UAVs (TUAVs). In this research, the term SUAV is used routinely, but the descriptions are equally appropriate for both SUAV and TUAV design concepts and operation.

SUAV missions are often described as “what’s over the next hill?” Related questions might be “where are they?” or “how many are there?” SUAVs enable small, ground-based military units to perform intelligence, surveillance, and reconnaissance (ISR) missions, reducing the risk to mounted or dismounted troops who would otherwise perform the ISR mission. The objective is to extend the “eyes” of the unit over a greater

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<sup>18</sup> Michael E. McCauley, Ph.D., LT Panagiotis Matsangas, Hellenic Navy, *Human Systems Integration and Automation Issues in Small Unmanned Aerial Vehicles*, October 2004.

<sup>19</sup> Leonard and Drezner, 2002.

range, faster and with reduced risk to human life. According to the DoD Roadmap,<sup>20</sup> one of the five “historically validated UAV roles is small unit asset for over-the-hill reconnaissance.” SUAVs will be deployable at or near the front lines, at the company or platoon level, and “will provide the commander with what amounts to a pair of flying binoculars.”<sup>21</sup>

SUAVs provide electro-optical (EO) or infrared (IR) sensor data leading to the detection, classification, and identification of vehicles, people, and other tactically relevant objects. From the Human System Integration (HSI) perspective, it is important to note that SUAVs do not detect, classify, or identify anything - people do. The SUAV provides the video or IR imagery or other data that enables properly trained observers to perform the detection, classification, and identification functions.<sup>22</sup>

## **F. SUMMARY**

Chapter III generally describes the requirements determined for the UAV flight and mission control system. The section on UAV Mission Functions described the importance of utilities for analyzing various UAV FMSS capabilities such as VBTT, low-cost sensors, actuators and microcomputers. The next section discussed UAV Control System software and hardware characteristics. Also, this section gave a brief overview of the PVNT Mission Control System. The section on the Data Required to Support UAV FMCS defined requirements to support UAV FMCS. The final section focused on SUAVs that generally describe UAV's.

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<sup>20</sup> DoD Roadmap, 2002.

<sup>21</sup> DoD, 2002.

<sup>22</sup> Michael E. McCauley, Ph.D., LT Panagiotis Matsangas, Hellenic Navy, Human Systems Integration and Automation Issues in Small Unmanned Aerial Vehicles, October 2004.

## IV. DATA REPRESENTATIONS

### A. INTRODUCTION

One of the main goals is to find open sources of information for the digital topographic maps. This chapter gives the user the necessary knowledge required to gather source data quickly in compatible formats. This chapter also describes the mainstream data representations and formats available to the military and civilian developer.

### B. DATA COLLECTION

A tremendous number of terrain data representations exist for a myriad of uses. This chapter discusses common data representations, the availability and ease of use of each data representation type, and the organizations involved in developing the mainstream, common terrain data formats. Some of the main data formats are shown below.

**Bitmap** - a file containing a rectangular array of color values, as opposed to other formats that might store line-based raster information. Commonly used bitmap formats are Targa (TGA) and Windows bitmap (BMP). Bitmapped images are usually used for heightfields.

**DEM** - Digital Elevation Map. A file that contains topographical information over a set area. Information is usually stored as a text file and typically contains such information as the geographical location of the four corners of the data, the values of the highest and lowest points, and which units are used in the DEM to measure these points (typically arc-seconds and meters). The data consists of an array of numbers that tell the height at each point over the whole area.

**DRG** - Digital Raster Graphic. A digital image (not vector or topographical data), usually mapped to the coordinates on the globe where it appears. A DRG is often similar in appearance to a regular “roadmap” and may have names of locations, roads, rivers, and topographical features written directly on it, along with contour lines.

**GIF** - Graphics Interchange Format. Used for web graphics but rarely for height fields because, although GIF files have relatively good compression, they only allow up to 256 colors and are more difficult to read.

**Targa** - A bitmapped file format, usually with a TGA extension.<sup>23</sup>

**GeoTIFF** - represents an effort by over 160 different remote sensing, GIS, cartographic, and surveying related companies and organizations to establish a TIFF-based interchange format for georeferenced raster imagery.<sup>24</sup>

### **C. WEB TOPOGRAPHY**

The recent growth of geospatial information on the web has made it possible to access various maps and topographic imagery easily. By integrating these maps and imagery, it is possible to create intelligent images that combine the visual appeal and accuracy of imagery with the detailed attribution information often contained in diverse maps. However, accurately integrating maps and imagery from different data sources remains a challenging task because spatial data obtained from various data sources may have different projections and different accuracy levels. This thesis presents efficient techniques to obtain that data from the Internet.

The Internet has also triggered a move towards more specialized niche applications and services. Meeting the specific needs of these rapidly emerging applications and services requires software and technology that can adapt as quickly as possible. Open source technologies will clearly gain in favor as software is required to adapt in a timely manner for highly specialized projects.

The TerraServer web site is one of the world's largest online databases, providing free public access to a vast data store of topographic maps and aerial photographs of the United States. TerraServer is designed to work with commonly available computer systems and web browsers over slow-speed communications links. The TerraServer name is a play on words: “Terra” refers to the “earth” or “land” and also to the terabytes of map

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<sup>23</sup> Sean O'Malley, Topography Site <http://www.geocities.com/ffrog.geo/topography.html>, retrieved August 5, 2005.

<sup>24</sup> GeoTIFF, <http://www.remotesensing.org/geotiff/geotiff.html>, retrieved May 10, 2005.

images stored on the site. The maps and aerial photographs can be downloaded into a graphics program, downloaded into a GIS, printed, or viewed on the computer screen. The maps available on the site are USGS topographic maps at the following scales: 1:24,000, 1:100,000 and 1:250,000 (Alaska and Hawaii at other scales). The site allows for zooming in on the maps to a resolution of 2 meters. The aerial photographs available on the site are USGS aerial photographs shown at 1:40,000 scale. The site allows for zooming in on the photographs to a resolution of 1 meter.

The maps are available for the entire United States. The photographs are available for approximately 90% of the United States. The maps and photographs are provided in the Universal Transverse Mercator (UTM) coordinate system.<sup>25</sup>

Tables 1 and 2 offer two quick Internet and address reference guides for digital topographic resources in easy-to-use format scales like 1:22,000 and more. This information is helpful for a researcher (operator) to find the necessary map layer, transfer it to the PVNT accepted format, and easily translate it with image correction tools to the bitmap format.

Table 1. Internet Reference Guides for Digital Topographic Resources 1:50,000 Scale.

Online Cartographic Resources	Description type	Contact	Price	Availability
<b>WORLD RESOURCES ALL COUNTRIES</b>				
<a href="http://casil.ucdavis.edu/casil/gis.ca.gov/drg/1x2_degree_series_albers_nad27_trimmed/">http://casil.ucdavis.edu/casil/gis.ca.gov/drg/1x2_degree_series_albers_nad27_trimmed/</a>	Digital raster graphics	California GIS Council 900N St. Sacramento, CA, 95814 (916) 653-1369	Free of charge	Open source
<a href="http://oddens.geog.uu.nl/index.php">http://oddens.geog.uu.nl/index.php</a>	Different types of formats of topographic maps and atlases	University of Utrecht, faculty of Geosciences	Free of charge	Open source search engine - one of the best cartographic search tools
<a href="http://library.ucsc.edu/maps/ucsmg/soviet.html">http://library.ucsc.edu/maps/ucsmg/soviet.html</a>	Soviet military topographic maps Set	University of California Libraries	Free of charge	Open source
<a href="http://peaklist.org/misc/links_to_map_resou">http://peaklist.org/misc/links_to_map_resou</a>	Miscellaneous topographic maps	Private collection of world	Free of charge	Open Internet

<sup>25</sup> TerraServer-USA, <http://terraserver-usa.com>, retrieved August 14, 2005.

Online Cartographic Resources	Description type	Contact	Price	Availability
<a href="http://rces.h">rces.h</a>	and research tools	topographic map resources		source
<a href="http://www.dscr.dla.mil/rmf/products/topo/50000.htm">http://www.dscr.dla.mil/rmf/products/topo/50000.htm</a>	1:50,000 Maps	279-3599 (local) or toll free at 1-888-3CLOSED (325-6733) 1-800-828-1120	Free of charge	Strictly access based military installation maps
<a href="http://www.lib.berkeley.edu/EART/topo.html">http://www.lib.berkeley.edu/EART/topo.html</a>	1:50,000 Maps	Earth Sciences and Map from all over the world	Free of charge Available on DVD and on-line Library University of California, Berkley	Library access based
<a href="http://www.maps2anywhere.com/Maps/maps_index.htm">http://www.maps2anywhere.com/Maps/maps_index.htm</a>	Over 10,000 maps are listed in an easy-to-use format - scale from 1:22,000	TRAVELLER'S RESOURCE GUIDE Great Journeys P.O. Box 9069 Masaryktown, FL 34604 America	From \$17 depends from country	Commercial products
<a href="http://www.landinfo.com/products_topos.htm">http://www.landinfo.com/products_topos.htm</a>	1:50,000 for 152 countries	<a href="mailto:sales@landinfo.com">sales@landinfo.com</a> Tel. (303) 790-9730 Fax. (303) 790-9734	Prices different \$249 for layer	Commercial products
<b>AFRICA</b>				
<a href="http://www.maps2anywhere.com/Maps/maps_index.htm">http://www.maps2anywhere.com/Maps/maps_index.htm</a>	Over 10,000 maps are listed in an easy-to-use format - scale from 1:22,000	TRAVELLER'S RESOURCE GUIDE Great Journeys P. O. Box 9069 Masaryktown, FL 34604 America	From \$17 depends from country	Commercial maps
<a href="http://www.webworldindex.com/cgi-bin/pseek/search2.cgi">http://www.webworldindex.com/cgi-bin/pseek/search2.cgi</a>	Maps from all over the world	Web World directory Search Engine	For commercial products	Search engine
<a href="http://www.omnimap.com/catalog/int/safrica.htm">http://www.omnimap.com/catalog/int/safrica.htm</a>	1:50,000 maps	1004 S. Mebane St. P.O. Box 2096 Burlington, NC 27216-2096, USA Tel: (336) 227-8300 (336) 227-8300 Fax: (336) 227-3748	Prices are different from \$12.95 per specified sheet	Commercial maps

Online Cartographic Resources	Description type	Contact	Price	Availability
<a href="http://www.mapmart.com/Topo/Raster.htm">http://www.mapmart.com/Topo/Raster.htm</a>	1:24,000 maps	USGS contact Rebecca J. Murray at (303) 759-5050 Ext. 175 or by e-mail at <a href="mailto:rjmurray@mapmart.com">rjmurray@mapmart.com</a>	Prices from \$14 original USGS topographic maps \$10 scanned USGS plot per sheet	Commercial maps
<a href="http://libweb.uoregon.edu/guides/intlstudies/africa.html">http://libweb.uoregon.edu/guides/intlstudies/africa.html</a>	1:50,000 maps	University of Oregon Libraries	Free	Library access
<b>NORTH AMERICA</b>				
<a href="http://www.cdmaps.com">http://www.cdmaps.com</a>	Maps on CD	PO Box 45083 Rio Rancho, NM 87174	\$15 per region plus \$5 for shipment	Commercial maps
<a href="http://maps.nationalgeographic.com/ngmaps/products.cfm">http://maps.nationalgeographic.com/ngmaps/products.cfm</a>	USA Regional Maps and some countries maps	National Geographic Society 1145 17 <sup>th</sup> St., N.W. Washington, D.C. 20036-4688	From \$99.95	Commercial maps
<a href="http://maps.nationalgeographic.com/ngmaps/contact.cfm?topocontact=ves">http://maps.nationalgeographic.com/ngmaps/contact.cfm?topocontact=ves</a>	U.S. regional maps and some countries maps on CD ROMs	National Geographic Society 1145 17 <sup>th</sup> St., N.W. Washington, D.C. 20036-4688	From \$99.95	Commercial maps
<a href="http://www.cis.ksu.edu/%7Edha5446/topoweb/paper.html">http://www.cis.ksu.edu/%7Edha5446/topoweb/paper.html</a>	U.S. paper maps collection	Private collection	From \$19.95	Commercial maps
<a href="http://www.mapadventures.com">http://www.mapadventures.com</a>	U.S. paper maps collection 1:50,000 maps		From \$4.95 per sheet plus shipment	Commercial maps
<b>EUROPE</b>				
<a href="http://mtopomap.nard.ru">http://mtopomap.nard.ru</a>	Different types of formats of topographic maps and atlases	Collection	Depends on reference	Open source
<a href="http://www.lib.berkeley.edu/EART/tour/topo.html">http://www.lib.berkeley.edu/EART/tour/topo.html</a>	1:50,000 maps from Europe and some other countries	Earth Sciences and Map Library University of California, Berkeley	Free of charge	Available on DVD and on-line library access based
<a href="http://www.bl.uk/services/reading/mapopenaccess.html">http://www.bl.uk/services/reading/mapopenaccess.html</a>	1:25,000 and 1:50,000 rich British maps collection	The British Library +44(0)870 444 1500 St. Pancras	Library resources mostly free	Rich database

Online Cartographic Resources	Description type	Contact	Price	Availability
		96 Euston Rd. London NW1		
<a href="http://www.memory-map.co.uk/maps_uk_onland.htm">http://www.memory-map.co.uk/maps_uk_onland.htm</a>	1:50,000 maps of 12 regions of Europe	+44(0)870 740 9040	£39.95 per region	Commercial maps
<a href="http://peaklist.org/misc/links_to_map_resources.html">http://peaklist.org/misc/links_to_map_resources.html</a>	Miscellaneous topographic maps 1:250,000 and better FREE topographic maps and research tools	Private collection of world topographic map resources and map collections	Free of charge	Open Internet source
<b>ASIA</b>				
<a href="http://www.omnimap.com/catalog/int/ind-topo.htm#p4">http://www.omnimap.com/catalog/int/ind-topo.htm#p4</a>	1:50,000 maps for Asian countries	Indonesia Topo Map Series	\$25.00 for piece	Commercial maps
<a href="http://cina-resources.net/ch0ps/regional.htm">http://cina-resources.net/ch0ps/regional.htm</a>	China and Asia	China maps	From \$300.00 for combined resource	Commercial products
<a href="http://www.oskarsb.ru/geor/asia.html">http://www.oskarsb.ru/geor/asia.html</a>	1:50,000 maps for several Asian countries	Russian General Staff maps	Free of charge	Open source
<a href="http://oddens.geog.uu.nl/index.php">http://oddens.geog.uu.nl/index.php</a>	All types of topographic	University of Utrecht faculty of Geosciences	Free of charge	Open source search engine - one of the best cartographic search tools
<b>SOUTH PACIFIC</b>				
<a href="http://www.asian.gu.edu.au/price.html#afghan">http://www.asian.gu.edu.au/price.html#afghan</a>	Miscellaneous 1:50,000 maps for different regions of the world	The Australian Centre of the Asian Spatial Information and analysis Network (ACASIAN) MAS, Griffith University Nathan (Brisbane), QLD 4111 Australia	Commercial products prices - data sets can be supplied on CD-ROMs, 100MB zip disks U.S. \$100	Open source
<a href="http://www.libraries.psu.edu/maps/paptopo.htm#australia">http://www.libraries.psu.edu/maps/paptopo.htm#australia</a>	Miscellaneous 1:50,000 maps	E-001 Paterno Library, University Park, PA 16802 Tel: (814) 863-0094	Free for library members	Library members free access
<b>RUSSIAN MAPS</b>				
<a href="http://zanzibar.ru/links/map_links.htm">http://zanzibar.ru/links/map_links.htm</a>	This is a link for open source Russian topographic maps Database and	References on most popular open source Russian Internet	Free	Open source

Online Cartographic Resources	Description type	Contact	Price	Availability
	references	topography (Andrey Belyakov)		
<a href="ftp://208.4.68.5/World Maps Russian Database">ftp://208.4.68.5/World Maps Russian Database</a>	World Database	Andrey Belyakov	Free	Open source
<a href="ftp://208.4.68.5/07_0803/Pakistan">ftp://208.4.68.5/07_0803/Pakistan</a>	Pakistan map	Andrey Belyakov	Free	Open source
<a href="ftp://208.4.68.5/Afghanistan/">ftp://208.4.68.5/Afghanistan/</a>	Afghanistan map	Andrey Belyakov	Free	Open source
<a href="ftp://208.4.68.5/Venezuela">ftp://208.4.68.5/Venezuela</a>	Venezuela map	Andrey Belyakov	Free	Open source
<a href="ftp://208.4.68.5/North Korea">ftp://208.4.68.5/North Korea</a>	North Korea map	Andrey Belyakov	Free	Open source
<a href="ftp://208.4.68.5/countries/China">ftp://208.4.68.5/countries/China</a>	China map	Andrey Belyakov	Free	Open source
<a href="http://topograf.h1.ru">http://topograf.h1.ru</a>	Military topography guide	Russian Information Agency	Free	Open source
<a href="http://library.ucsc.edu/maps/ucsmg/soviet.html">http://library.ucsc.edu/maps/ucsmg/soviet.html</a>	Soviet military topographic maps set	University of California Library	Free	Open source

Table 2. U.S. Universities Research and Education Topographic Libraries, Address Reference Guides for Digital Topographic Resources. All information on topographic maps described is available on CD disks.  
From: <http://library.ucsc.edu/maps/ucsmg/quick.html>

Name and Address of Institution	Map Room Contact Person	Central Interlibrary Loan Lending (ILL) Contact Person	Lending Policy
<b>Stanford University</b> <a href="#">Branner Library</a> 201 Mitchell Bldg. MC-2211 397 Panama Mall Stanford, CA 94305	Julie Sweetkind-Singer sweetkind@stanford.edu (650) 725-1102 (650) 725-2534 (fax)	Chris Harrison  Alex Rajeff	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Berkeley</b> <a href="#">Earth Sciences &amp; Map Library</a> 50 McCone Hall Berkeley, CA 94720-4767	Fatemah Van Buren fvanbure@library.berkeley.edu (510) 643-9350 (510) 643-6576 (fax)	Same Alternate: Traci Penrod tpenrod@library.berkeley.edu (510) 643-9350 (510) 643-6576 (fax)	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Berkeley</b> <a href="#">Water Resource Center Archive</a> 410 O'Brien Hall	Linda Vida lvida@library.berkeley.edu (510) 642-2666 (510) 642-9143 (fax)	Katie Hornstein khornste@library.berkeley.edu (510) 642-2666 (510) 642-9143(fax)	Request directly from Map Library by e-mail, telephone,

<b>Name and Address of Institution</b>	<b>Map Room Contact Person</b>	<b>Central Interlibrary Loan Lending (ILL) Contact Person</b>	<b>Lending Policy</b>
Berkeley, CA 94720			or fax
<b>UC Davis</b> <a href="#">Map Collection</a> Government Information and Maps Department Shields Library 100 N.W. Quad University of California Davis, CA 95616-5292	Kathy Stroud kpstroud@ucdavis.edu (530) 752-5248 (530) 752-3148 (fax)	Same	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Irvine</b> <a href="#">Government Publications &amp; Microforms</a> P.O. Box 19557 Irvine, CA 92713	Yvonne Wilson ymwilson@lib.uci.edu (949) 824-7362 (949) 824-2542 (fax)	Same	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Los Angeles</b> <a href="#">Henry J. Bruman Map Collection</a> Collections, Research and Instructional Services Room A4510 URL Box 951575 University of California Los Angeles, CA 90095-1575	David Deckelbaum ddeckelb@library.ucla.edu (310) 825-1088 (310) 825-6795 (FAX)		Request directly from Map Library by e-mail, telephone, or fax
<b>UC Los Angeles</b> <a href="#">Science &amp; Engineering Library, Geology &amp; Geophysics Collection</a> 405 Hilgard Los Angeles, CA 90095	Anthony Ragan aragan@library.ucla.edu (310) 825-1055 (310) 825-6485	Paul Camp ecz5rar@mvs.oac.ucla.edu (310) 825-3646	Request directly from Central ILL
<b>UC Riverside</b> <a href="#">Government Publications</a> Riverside, CA 92517	Rick Beaumont rickb@ucr.ac1.ucr.edu (951) 827-3226	Janet Moores jmoores@ucr.ac1.ucr.edu (951) 827-3234 (951) 827-3285 (fax)	Request directly from Map Library
<b>UC Riverside</b> <a href="#">Physical Sciences Library -- Map Collection</a> 1345 Geology Bldg. Riverside, CA	Wendie Helms Wendie.Helms@ucr.edu (951) 827-6423 (951) 827-2223	Sandra Eberhardt (951) 827-3238	Request directly from Central ILL (geological maps only)

<b>Name and Address of Institution</b>	<b>Map Room Contact Person</b>	<b>Central Interlibrary Loan Lending (ILL) Contact Person</b>	<b>Lending Policy</b>
92517			
<b>UC San Diego</b> <a href="#">Scripps Institution of Oceanography Library</a> 9500 Gilman Drive, Dept. 0219 La Jolla, CA 92093-0219	Peter Brueggeman siolib@sio.ucsd.edu (858) 534-1230 (858) 534-5269 (fax)	SIO ILL scrippsill@ucsd.edu (858) 534-1232 (858) 534-5269 (fax)	Request directly from SIO ILL by email, telephone, or fax
<b>UC San Diego</b> Social Sciences and Humanities Library <a href="#">Map Room, 0175R</a> La Jolla, CA 92093-0175	Larry Cruse Larry@library.ucsd.edu (858) 534-1248 (858) 534-7548 (fax)	Brad Altman ILL: (858) 534-2528	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Santa Barbara</b> <a href="#">Map &amp; Imagery Laboratory</a> University Library Santa Barbara, CA 93106	Mary Larsgaard mary@library.ucsb.edu (805) 893-4049 (805) 893-8799 (fax)	Same	Request directly from Map Library by e-mail, telephone, or fax
<b>UC Santa Cruz</b> <a href="#">Map Room</a> Science Library Room 130 University of California Santa Cruz, CA 95064	Cynthia Jahns cjahns@ucsc.edu (831) 459-3187 (831) 459-4187 (fax)	Alternate: Laura Campbell laurac@ucsc.edu (831) 459-4117 (831) 459-4187 (fax)	Request directly from Map Library by e-mail, telephone, or fax
<b>Univ. of Nevada - Reno</b> <a href="#">Mary B. Ansari Map Library</a> DeLaMare Library/MS 262 1664 N. Virginia St. Reno, NV 89557-0044	Linda Newman lnewman@admin.unr.edu (775) 784-6945 ext. 20 (775) 784-6949(fax)	Same	Request directly from Map Library by e-mail, telephone, or fax

#### **D. EXAMPLES OF TOPOGRAPHIC MAPS**

One of the requirements of this thesis research is to collect web addresses and references in order to provide examples of topographic maps. Tables 1 and 2 lists sites and addresses for web-based topographic research maps. This section discusses a subset of map sources and download institutions.

## 1. Soviet Maps

In order to obtain Soviet military installation maps, go to <http://www.lib.berkeley.edu/EART/topo.html> and open Albania, then click on the area needed. To download a file, right click on the image and save the picture in the bmp format (see Figure 11).

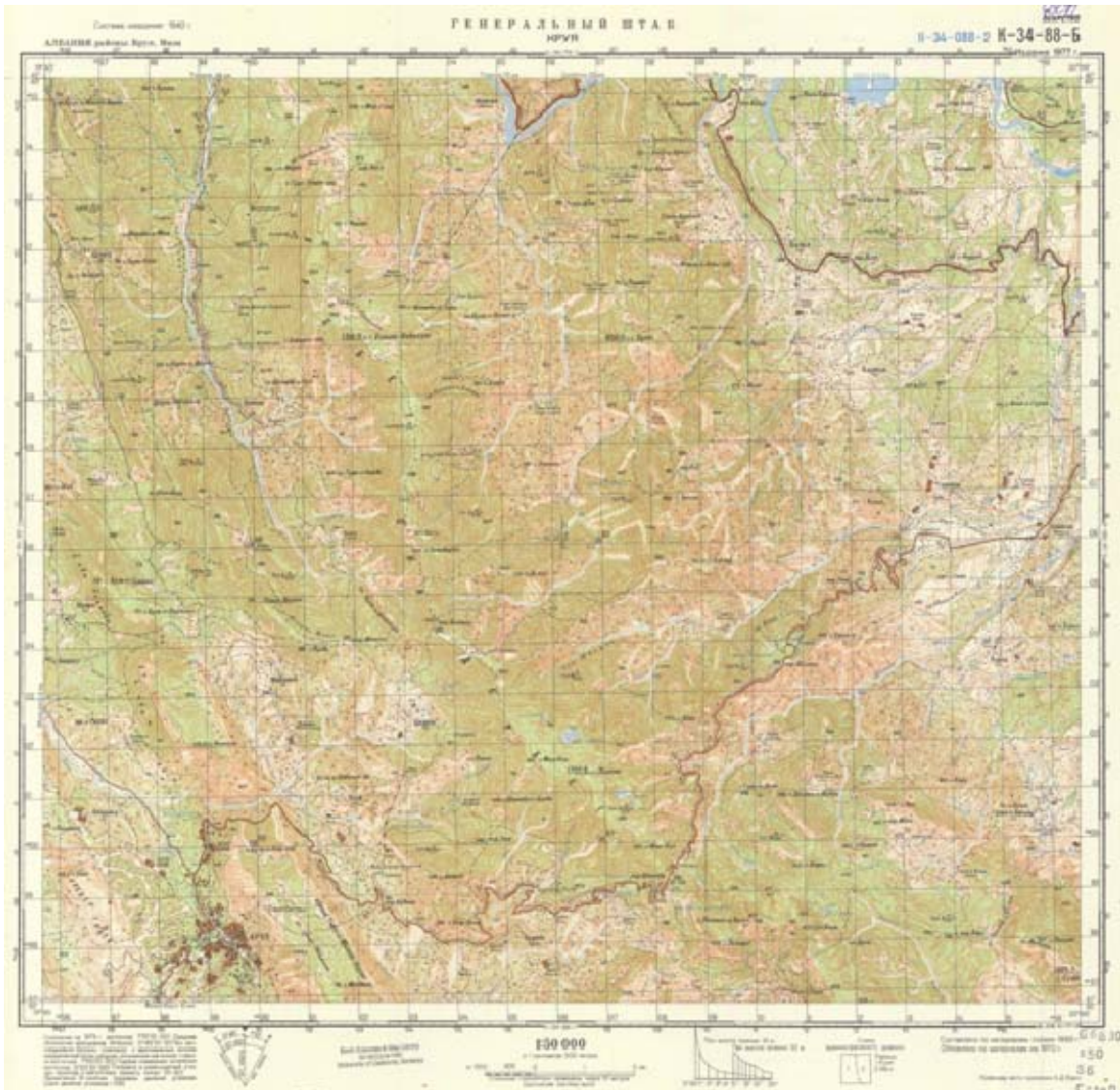


Figure 11. Soviet Military Installation Maps.

## 2. African Maps

In order to obtain an African map, go to <http://www.omnimap.com/catalog/int/safrica.htm> and open South Africa 1:50000 then click South African area 65-3052 sample and download the area needed. To download the file, right click on the image and save picture in the bmp format. Since this is a commercial site, payment is required to obtain these types of maps. Figure 12 shows an example of the African maps.

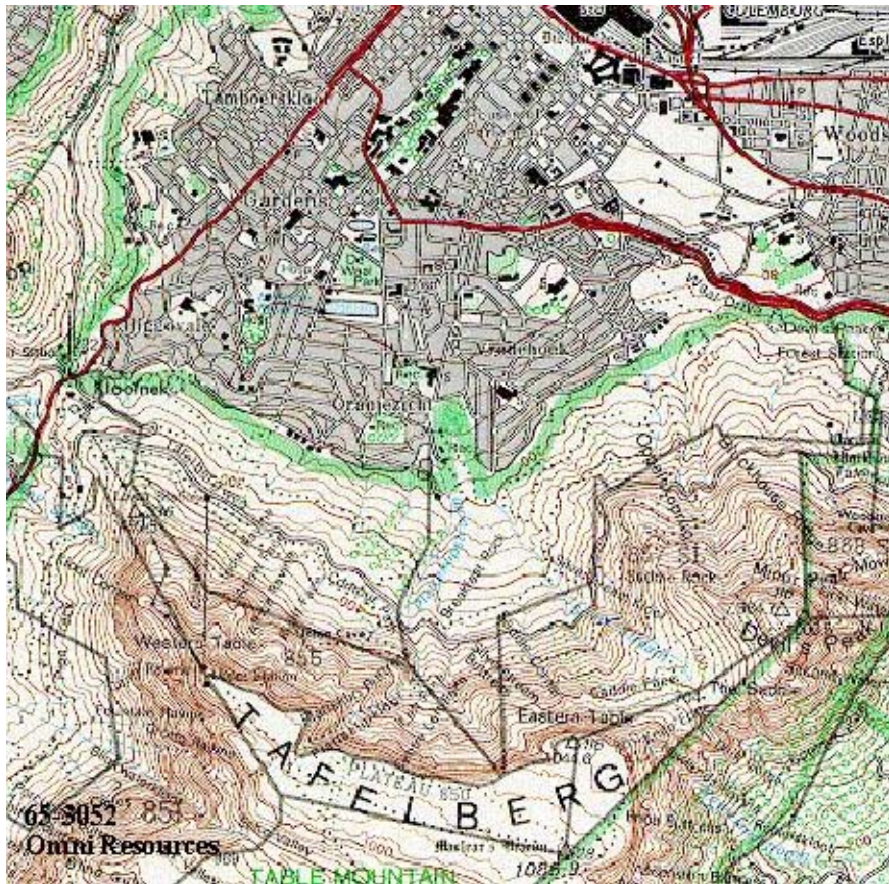


Figure 12. African Topographic Maps.

### 3. North American Maps

In order to obtain North American maps, go to <http://www.topowest.com/California/state.html> (Figure 13) and open California 1:50000, then click the San Luis Obispo region example and download the area needed. To download the file, right click on the image and save the picture in the bmp format. As this is a commercial site, payment is required to obtain these types of maps.

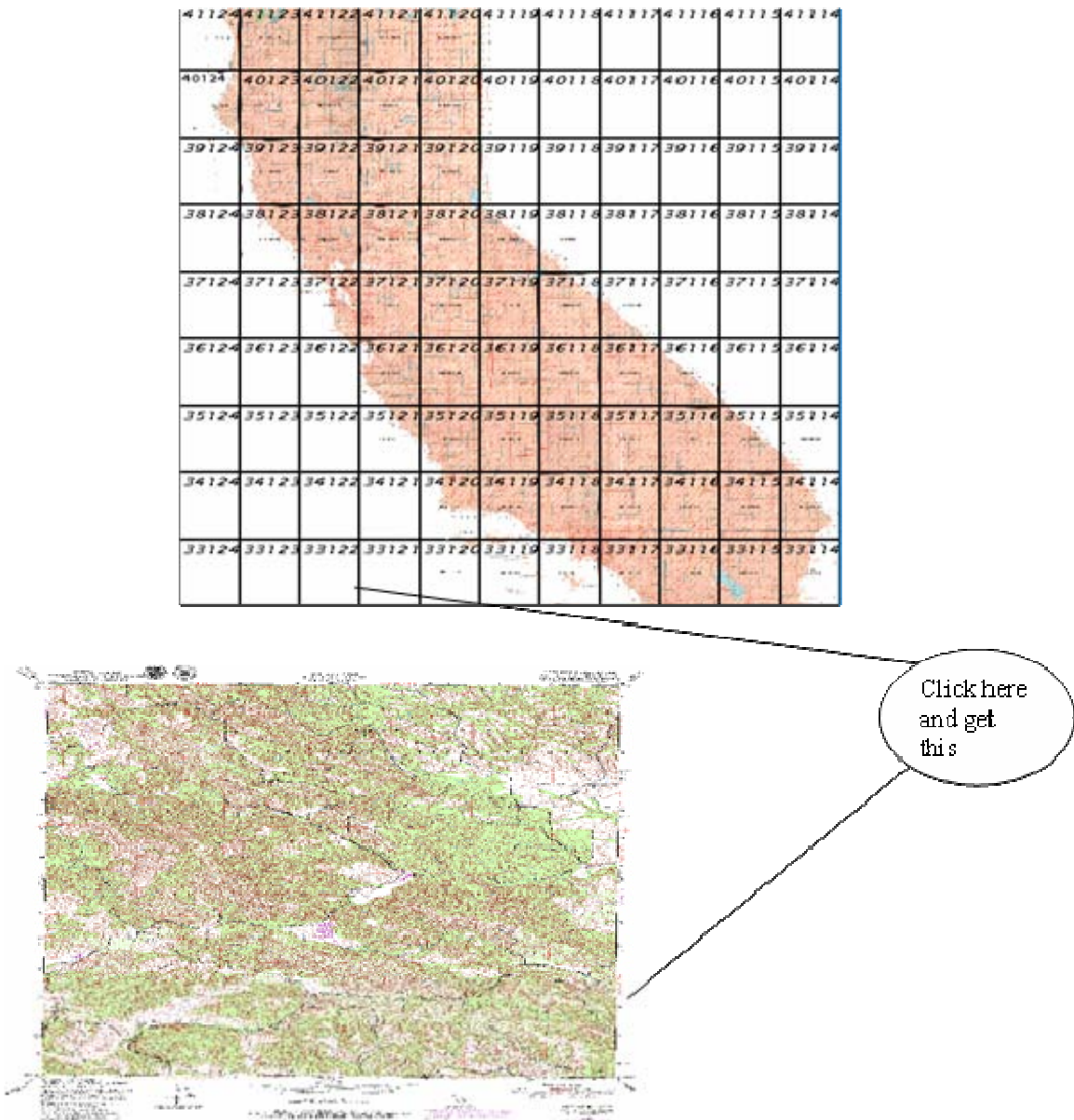


Figure 13. North American Topographic Maps.

#### 4. European Maps

For European maps, one of the best reference sites is <http://www.austrianmap.at/>. Open Austria, then zoom the map to 1:50,000 scale and save it using keyboard buttons Ctrl+prt screen and save it in the bmp format.

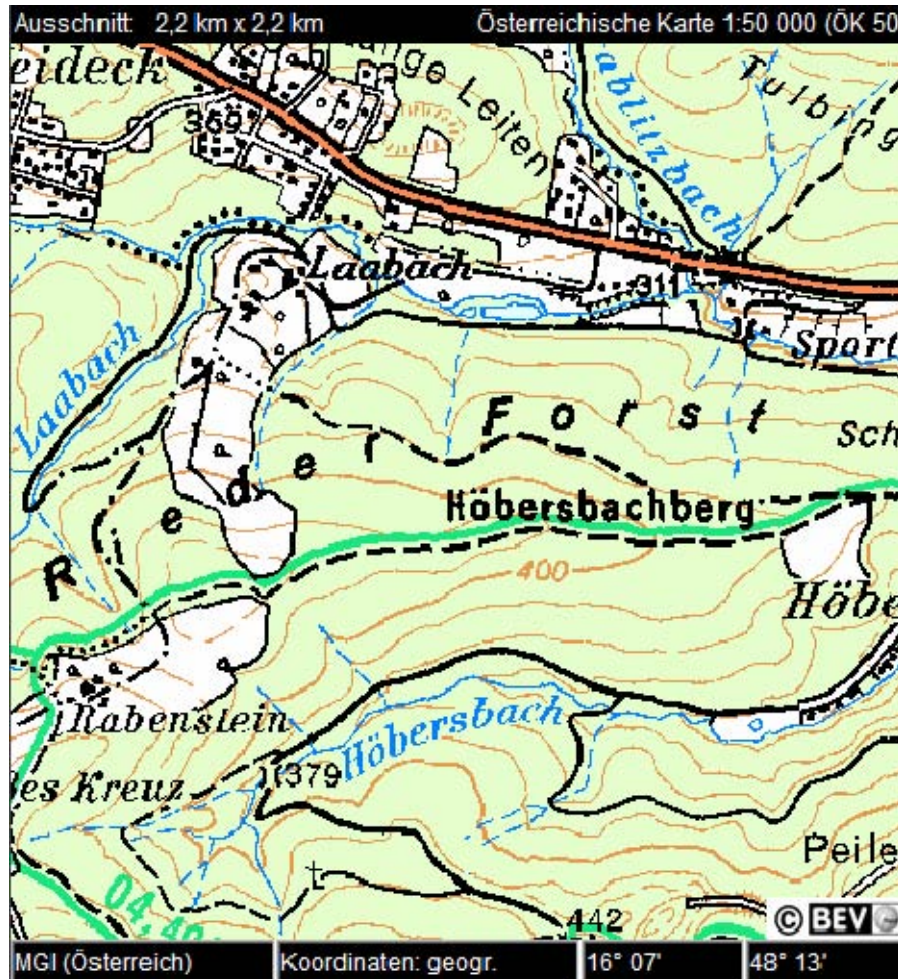


Figure 14. European Topographic Maps.

## 5. Asian Maps

For Asian maps, one of the best reference sites is <http://www.omnimap.com/catalog/int/ind-topo.htm#p4>. Open the sample map at <http://www.omnimap.com/cgi-bin/omni/graphic.pl?images/for-topo/647751sw.jpg> and save it in the bmp format.



Figure 15. Asian Topographic Maps.

## E. NAVAL POSTGRADUATE SCHOOL (NPS) MAP SUPPORT

NPS has an excellent site that provides a guide to maps, nautical charts, and digital data tools at <http://library.nps.navy.mil/home/mapcollection.htm>. This reference is part of the Dudley Knox Library's Map Collection (Figure 16). The collection supports and enhances the research and scholarship of NPS curricula by providing visual and geographic coordination of data. The site includes an extensive guide to maps on the web,

categorized by geographic region. Categories include global, all continents, and oceans. This site also includes a large number of web references different types of maps, such as military maps, digital data and tools, topographic maps, commercial maps, and reference tools.<sup>26</sup>

Moreover, this site is connected with TerraServer.com, which is the one of the popular online sources for overhead imagery. It has the largest online atlas of high-resolution satellite imagery and aerial photography. The PVNT operator can use this site reference as a primary digital topographic source.



Figure 16. NPS Dudley Knox Library Web Site.

## 1. Internet Resources for Topographic Maps

One of the valuable tools of the NPS Map Collection is the reference list entitled "Internet Resources for Topographic Maps". The MapFinder Internet site provides a wide variety of topographic maps in digital format. The USGS index site allows a user to

<sup>26</sup> Dudley Knox Library's Map Collection, retrieved October 6, 2005 from <http://library.nps.navy.mil/home/mapcollection.htm>.

search their 7.5 minute printed paper maps by either entering the name of a populated place, entering a zip code, or clicking on a map.<sup>27</sup>

Also, it is necessary to mention the Topofinder map search engine site, which is a service provided by MapQuest. This page allows for city and state searching to determine the USGS Topo Quad of interest. Moreover, there are several map collection references like Topozone and the United States Geological Survey, which are helpful in finding necessary maps. Using USGS maps, this site offers interactive topographic maps of the entire United States.<sup>28</sup>

## **2. Buying Maps**

Nowadays, it is possible to buy some maps directly from the Internet. The NPS Map Collection lists several commercial mapping sites. There are hundreds of map dealers globally. This list is not intended to be comprehensive; it is simply a small representative collection of what is available online. For example, [www.Eastview.com](http://www.Eastview.com)<sup>29</sup> provides map information regarding Russian and Chinese map sources and the Russian Archive Project, which will create a digital database of regional and national guides to the Russian Archives. The project will digitize both the printed and handwritten guides to approximately 105 central and regional archives in Russia (with a total of 37,829 pages). This digital database provides the most comprehensive access to the holdings of the entire Russian archive system in one simple, user-friendly electronic format.<sup>30</sup>

Last but not least, one of the good sites listed on the NPS Map Collection reference site is [www.Maps.com](http://www.Maps.com). This site allows a user to search by keyword or to browse through different geographic regions. It also displays a digital image of most of the maps.

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<sup>27</sup> Dudley Knox Library's Map Collection, retrieved October 17, 2005 from <http://library.nps.navy.mil/home/mapcollection.htm>.

<sup>28</sup> Dudley Knox Library's Map Collection, retrieved October 17, 2005 from <http://library.nps.navy.mil/home/mapcollection.htm>.

<sup>29</sup> Eastview Information Services, retrieved October 17, 2005 from <http://www.eastview.com/>.

<sup>30</sup> <http://online.eastview.com/projects/ticfia/index.html>, retrieved October 17, 2005.

### 3. Directories

As the thesis provided earlier in Table 2 there are useful university links called Directories - lists of online maps. If a user was unable to find a useful map using the links previously mentioned in this thesis, browsing these directories may help. Some of these directories are cited in the NPS Map Collection, as listed below.

[Air University Library: Map Sites](#). Links are to other directories and are arranged by city, state, country, world, historical, and directional.

[Atlapedia Online](#). Atlapedia Online contains full color physical and political maps, as well as key facts and statistics on countries of the world.

[Alexandria Digital Library \(ADL\)](#). This is Project Alexandria's Other-Sites Index. Organized like a directory tree, beginning with the universe, the sites are classified by location, then by theme or type. The entire index can be browsed by subject or by title.

[CIA Factbook Reference Maps](#). Sixteen regional maps

[ePodunk](#). ePodunk provides in-depth information about more than 25,000 communities around the country, from Manhattan to Los Angeles, Pottstown to Podunk. The listings also include geocoded information about thousands of parks, museums, historical sites, colleges, schools and other places across America.

[Historical Maps](#). The David Rumsey Collection focuses on 18<sup>th</sup> and 19<sup>th</sup> century North and South American cartographic materials. The collection includes atlases, globes, school geographies, maritime charts, and a variety of separate maps, including pocket, wall, and manuscript maps.

[Infomine](#). An University of California (UC) Riverside project that indexes map-related web sites and provides abstracts. These are organized by table of contents/subject/keyword/title and are searchable.

[National Land Survey Organizations and Mapping Agencies](#)

[United Nations](#) Cartographic Section. A large list of online maps, including peacekeeping maps, thematic maps, and general maps.

[UTexas: Map Related Web Sites](#). Alphabetical list of maps grouped by city, state, country, general, weather, and historical maps.

[Utrecht University, The Netherlands: Odden'sBookmarks: The Fascinating World of Maps and Mapping](#). Comprehensive international coverage. There is a well organized table of contents but the site is very large and can be confusing at times.<sup>31</sup>

#### **4. Finding Maps**

During map searching, it is necessary to know about specific Internet search engines for spatial databases. The NPS Map Collection references several such search engines, as list below.

[GeoIndex](#). A specific search engine covering geotechnical, environmental, hydrogeology, geology, mining, and petroleum topics. Lists of companies, associations, education, and government can also be browsed.

[Infomine](#). This UC Riverside Project indexes and abstracts map-related web sites. Searching can be done by subject/keyword/title/author or by browsing through the table of contents/subject/keyword/title lists.

Search Ways for Maps on the Internet. The Swiss Federal Institute of Technology Zurich's Library provides a list of resources categorized by special searches for maps on the Internet, general search machines, special search fields, and online library catalogues and services in Britain and Ireland maintained by National Information Services and Systems (NISS).

Stanford: Searching for Maps . Provides ideas on searching for maps in Socrates, Stanford's online catalog. Many of these tips can carry over into other databases.<sup>32</sup>

Internet Resources for Military Maps. This part of the NPS Map Collection provides Military Installation Maps. Some of these maps are available with access, some of them are free, and some of them are available for a fee.

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<sup>31</sup> Dudley Knox Library's Map Collection, retrieved October 17, 2005 from <http://library.nps.navy.mil/home/mapcollection.htm>.

<sup>32</sup> Dudley Knox Library's Map Collection, retracted October 17, 2005 from <http://library.nps.navy.mil/home/mapcollection.htm>.

## **5. General**

[Arlington National Cemetery Map](#). U.S. Army Military District of Washington.

[Arlington National Cemetery Maps](#)

[Interactive Map](#)

[Index of Maps from Strategic Forecasting](#). STRATFOR.com

[Maps of National Historic Sites, Memorials, Military Parks and Battlefields](#).

Perry-Castaceda Library Map Collection, University of Texas at Austin.

[Military Battles and Campaigns](#). Library of Congress American Memory Collection

[Military History Maps](#). Section of the *Historical Maps of the United States* page from the Perry-Castaceda Library Map Collection, University of Texas at Austin

[Military Maps of Scotland \(18th century\)](#)

[Unified Command Plan Map](#)

[West Point Atlas of Military History: Index](#)

The information reviewed in this section points to a large number of potential map data sources. Ultimately, only those capable of being retrieved electronically with the auxiliary information so that the retrieved source data can be preserved into files satisfying the requirements specified in Table 5 area of interest.

## **F. SUMMARY**

This chapter mainly described special digital topographic formats necessary for the PVNT system. The Data Collection section gave information about the different types of digital terrain maps. The section on Web Topography describes geospatial data in tables, which could be easily searched from the Internet to find necessary map layers applicable to PVNT and that can be easily translated into the bit map format. The section on Topographic Maps Examples described examples of digital maps that were given in previous section tables. The NPS Map Support section mainly characterized local resources for map collections and databases.

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## **V. DATA PREPARATION SYSTEM**

### **A. INTRODUCTION**

This chapter describes the making of the virtual environment, the architecture of the system and the applications used in its development. The chapter shows, to a real user, digital map process steps necessary for the thesis experiment. Also, it shows how to use the data effectively, identifies necessary conversion tools, discusses how to use these tools to obtain final data, and finally how to import that data into the PVNT system.

### **B. DIGITAL MAP PROCESSING OVERVIEW**

#### **1. Data Processing Steps Necessary before the Experiment**

This step exercises the real data preparation system for this thesis experiment. Figure 17 illustrates the Digital Map Processing overview. Data from various sources may be available for map overlays. This source data is either in digital format or must be digitized into a set of source files containing the digital map data. These are called source files. The source files may be in various formats, covering disparate regions and containing differing information. The import preparation function is a combination of analysis, hand editing, and application of tools in order to prepare the source files for import into PVNT.

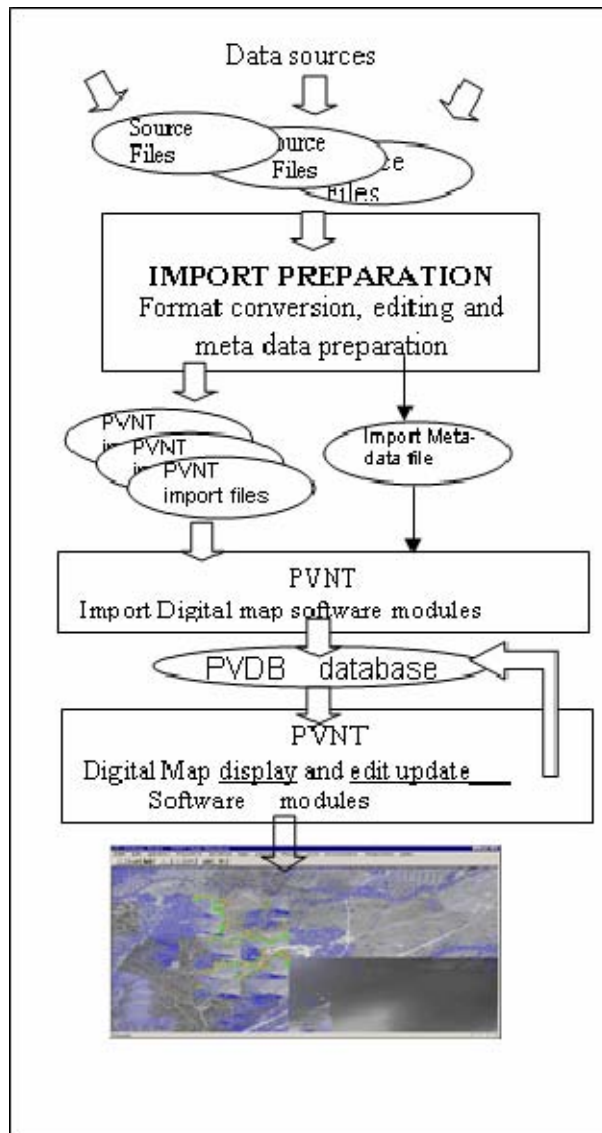


Figure 17. Digital Map Processing Overview.

The PVNT program only imports a limited number of formats and depends upon external software packages to perform the appropriate conversion. PVNT acceptable import files are Microsoft Bit Map format and must be geographically registered. The exact PVNT import file specification is available in Table 5. Since digital image files are very large, it is typical to provide such data in a file array. The details of such arrays are written into an Import Meta-data file as shown in Figure 35.

Import routines called interactively from the PVNT Terrain Import/Export Data dialog perform the job of loading the DMap layer in the PVDB runtime database for PVNT. Once in the PVDB database, editing tools are available for updating and correcting the map information.

Finally, map displays are used in PVNT to perform situational awareness, image-based targeting, and to produce three dimensional projection products and multi-layer maps.

A map used for the PVNT layer has a particular scale, such as 1:50000. This scale is used by the military for most military installation maps. Also, it is easy to orient PVNT operators to this scale. During the field experiment, the coordinate numerical prediction method based on real GPS targeting was used and this data compared with the PVNT image coordinate system. This thesis experiment utilized one of the oldest analytical methods used in Geographical Information Systems (GIS) – map overlay. Map overlay is the set of procedures by which maps with different themes are brought into geometric and scale alignment so that their information can be cross referenced and used to create more complex themes.<sup>33</sup>

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<sup>33</sup> Keith C. Clarke, "Getting Started with Geographic Information Systems," Prentice Hall Series, 2003, p. 170.

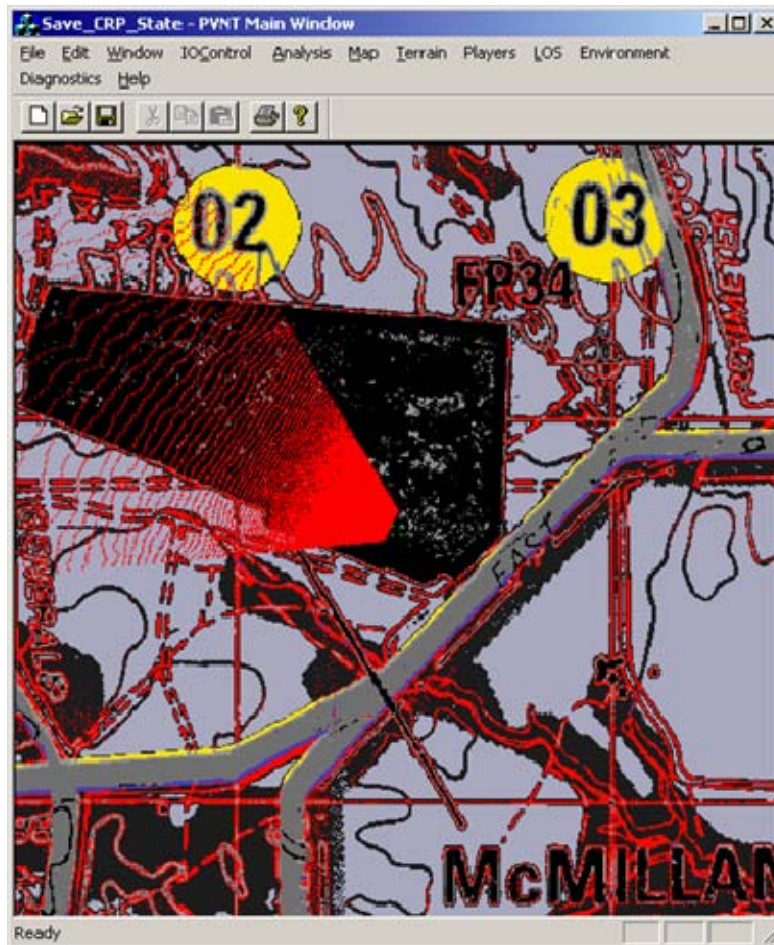


Figure 18. Map Overlay Produced in Thesis Experiment.

In accordance with the thesis experiment, the map overlay method was used to develop an image-based targeting system in PVNT system. One of the greatest achievements of the thesis is that this image-based targeting system can use real-world image data to obtain logical numerical data for modeling, analysis, and prediction.

The key to understanding geographical information is to obtain accurate data to examine the situation and make a decision.

### C. FORMAT CONVERSION AND DATA CORRECTION

This section describes the preliminary steps required to retrieve and convert source data identified in the last section to input files required by the PVNT program. Figure 19 shows the steps involved. The “identify source material” step was discussed in

the last section. The following paragraphs discuss the detailed operations and programs required to retrieve source data and prepare it in a format required by PVNT.

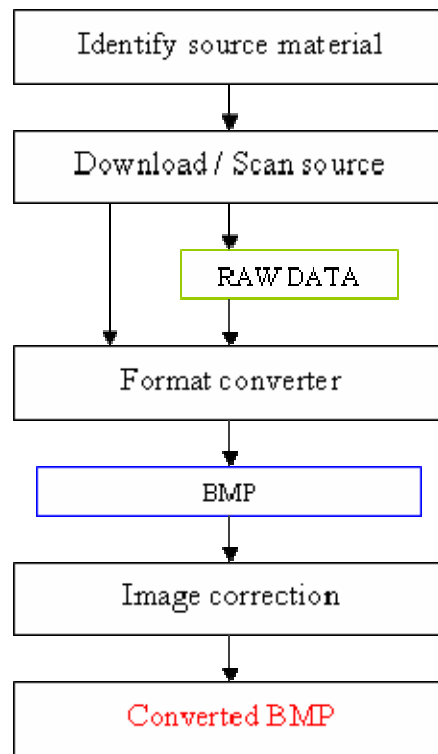


Figure 19. Format Correction and Data Correction Process.

Download source includes all forms of open source topographic maps that could be substituted with military installation maps. In order to gather information properly from the Internet and download the necessary digital topographic maps, the following computer specifications are required. The target PC must have an Internet connection (i.e., be able to connect directly to the World Wide Web). Table 3 shows the recommended specifications for a PC in order to download the maps.

Table 3. Recommended Specifications for a PC.

Item	Required	Recommended
Operating System	Windows 2000, Windows NT, XP	Windows XP
CPU	Pentium	(same)
Monitor Colors	256	65,536
Monitor Resolution	640 x 480	1024 x 768
RAM	512 MB	(same)
Hard Disk Available	60 GB	(250 GB)
Mouse	Yes	(same)
Printer	Color - configured for Windows	Laser plus Color
Scanner	Color - configured for Windows	(same)
Internet	Upload 300-500 kb/sec	(same)

Figure 20 shows the differences between raw data and the converted BMP map. All grids are visible and it is ready to split with another type of map. Scanning converted paper maps into a digital form. Each paper map can be scanned into one of many digital file formats (BMP, Tiff, PDF, Jpeg, Gif, etc.). In this case, data was scanned into the BMP format, which the PVNT system needs.

In addition, map digitizers have the ability to enhance, or sharpen scanned map imagery. This is required to improve the quality of digitized maps and adapt these maps formats to the PVNT system.



Only easily available programs were used in this thesis:

- Scanning – program to convert from hard copy into digital format
- Image converter – Home Plan Software for image conversion
- Paint – Microsoft Office Program
- Photoshop – Adobe Photoshop Album 3.0 Starter Edition
- Office Picture Manager - Microsoft Office Program

These programs are discussed in the following subsections.

## **1. Commercial and Free Software Programs**

### ***a. Scanning***

The source data for digitizing is a paper map, which is often available on the Internet or obtained from a library. Hence, the download function is actually carried out by hand transfer, and the “raw data” is the hard copy. For scanning, maps should be clean and free of folds and marks.

### ***b. Paint***

Paint is a drawing tool that can be used to convert downloaded maps into bitmap files. Paint can also be used to view and edit scanned maps. Figure 21 shows the Paint Application in which a map images file is inserted into the application in order to edit the file.

1. In the toolbox, click **Select** and then drag the pointer to define an area for the inserted file.
2. On the **Edit** menu, click **Paste From**.
3. Locate and double-click the file you want to insert.
4. Drag the image file to position it correctly, and then click outside the selection.

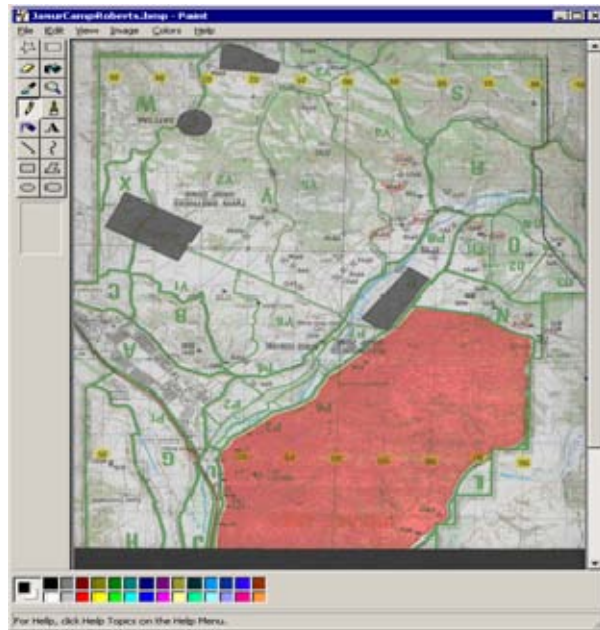


Figure 21. Example of Paint Application.

*c. Image Converter*

Image Converter is a fast and flexible image conversion program, supporting over 15 formats. It features over 20 effects that can be applied in any conversion process, and even in batch mode. The included Image Conversion Wizard helps with a step-by-step dialog that allows a user to select files, set conversion properties (JPG to BMP), apply effects, and set how the converted files will be named. Batch support in Image Converter allows a user to add thousands of images easily to be converted, and with a single click Image Converter can then convert, rename, and add effects in accordance with desired settings. To make the process simpler, Image Converter includes the MediaView Extension from SoftTech InterCorp for converting between image types and applying effects can be done by simply right-clicking an image. The user can convert and rotate 120 selected files right from Windows Explorer.

Image Converter supports writing to the following formats: JPG, GIF, PIC, TIF, BMP, DCX, DIB, JIF, PBM, PCX, PGM, PNG, PPM, TGA, and WPG. Supported effects that can be processed in batch mode include: Adjust HSL, Adjust RGB, Blend, Brightness, Buttonize, Color Depth, Contrast, Crop, Draw Text, Motion Blur, Mosaic, Perspective, Pinch, Posterize, Resample, Resize, Ripple, Rotate, Sharpen,

Soften, Solarize, Swirl, Auto Contrast, Blur, Diffuse, Dilate, Emboss, Equalize, Erode, Flip, Median, Mirror, Negate, Outline, Replace Colors, Colorize, and Merge.<sup>34</sup>

Figure 22 shows the Image Converter (commercial version) changes in a topographic image map before and after editing. During this thesis research, Image Converter's free version was obtained from the Internet. This is a very simple application where a user may easily and quickly convert one image format to another. Figure 23 shows the free version of Image Converter in action.

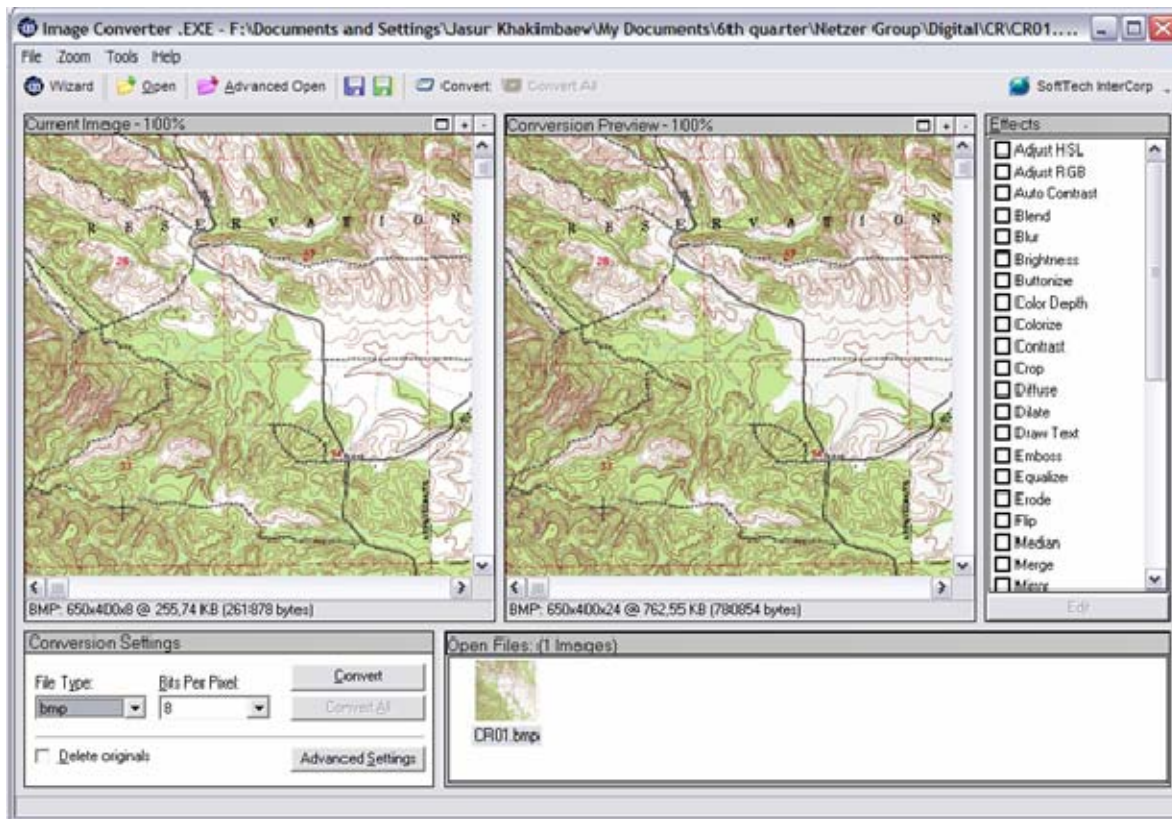


Figure 22. Commercial Version of Image Converter.

<sup>34</sup> SoftTech InterCorp, retrieved October 5, 2005 from <http://www.stintercorp.com/ic.php?app=ImageConverterEXE2074>.

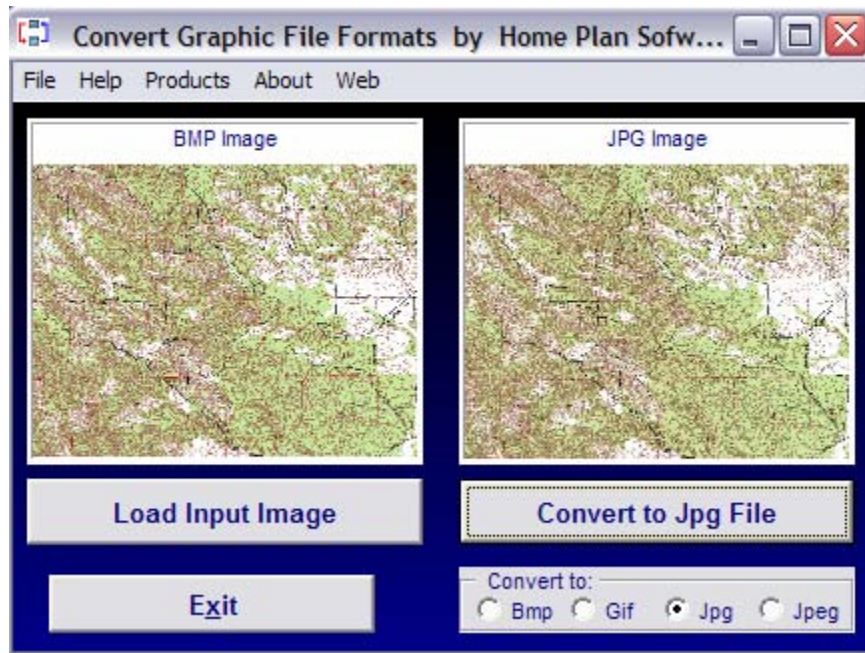


Figure 23. Free Version of Image Converter.<sup>35</sup>

*d. Photoshop*

Photoshop, or Adobe Photoshop Album Starter Edition 3.0, is used as a correction tool in order to edit downloaded or scanned maps. It is also used to convert map format, scale, rotate, resize, and so on. Figure 24 shows an example of Adobe Photoshop Album Starter Edition 3.0 in action.



Figure 24. Adobe Photoshop.

<sup>35</sup> <http://www.homeplansoftware.com/imgconv.htm>, retrieved October 4, 2005.



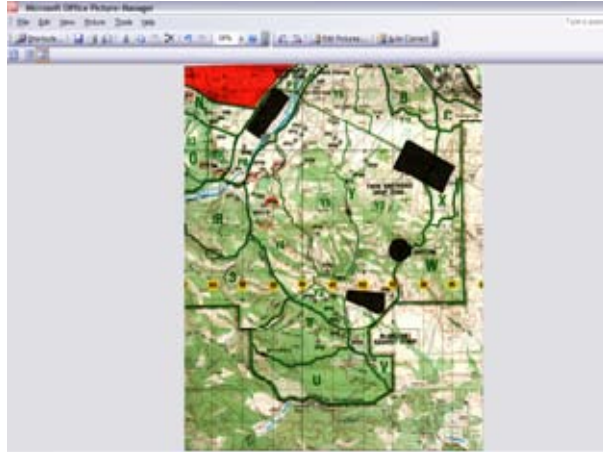


Figure 26. Microsoft Office Picture Manager.

## D. EXAMPLES

### 1. Camp Roberts Hard Copy Example

This section presents two specific examples of data retrieval conversion and correction. The first utilizes a digitizer to generate a BMP format for Camp Roberts (see Figure 27). The second uses an Internet source to generate files for a test site at Fort Hood.

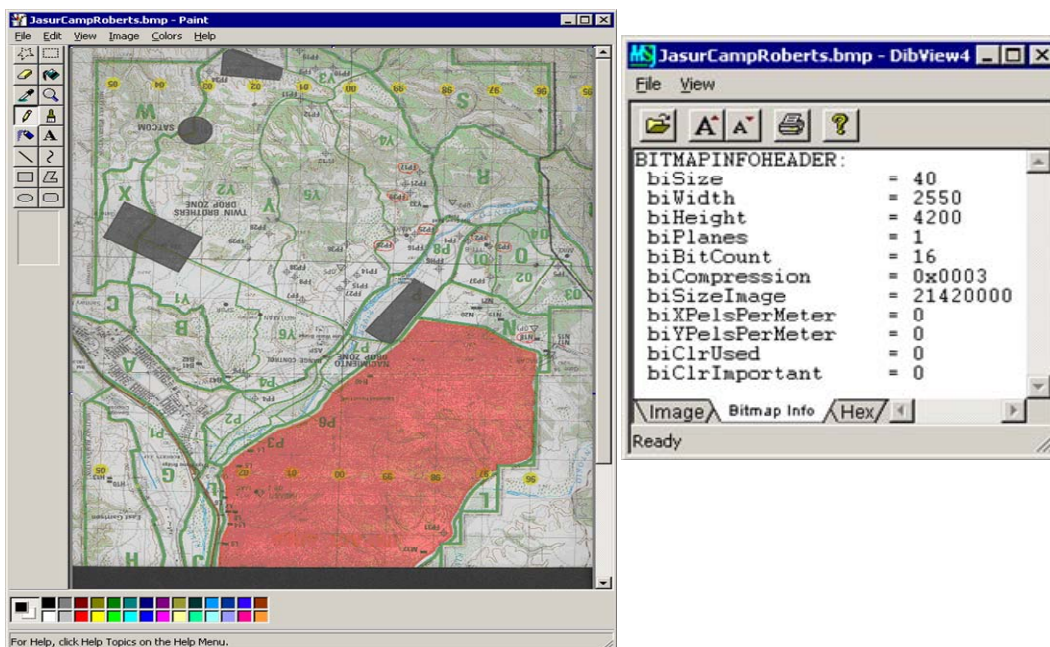


Figure 27. BMP Conversion.

The intent is to import this file into the PVNT. The required specifications are shown in the Table 5.

Table 5. PVNT Digital Map Input Format Specification.

<b><i>PVNT DIGITAL MAP INPUT FORMAT SPECIFICATION</i></b>		
<b>Description</b>	<b>Value / Unit</b>	<b>Parameter</b>
Format	BMP 19778	bftype
Number of colors used	16	biClrUsed
Bit Count	4	BiBitCount
Number of planes	1	BiPlanes
Compression	0	BiCompression
Color definition	16 RGB Pallet	
Resolution X	pixels per meter	biXPelsPerMeter
Resolution Y	pixels per meter	biYPelsPerMeter
Image size X	pixel Width	biWidth
Image size Y	pixel Height	biHeight
Scan direction	raster lower left	
Geographic registration parameters		
Lower left corner	7 digit Easting	in filename
Lower left corner	7 digit Northing	in filename
Size in X direction	Easting meters	(biXPelsPerMeter) * (biWidth)
Size in Y direction	Northing meters	(biYPelsPerMeter) * (biHeight)
Shape	rectangle	
Offset to first byte of image		bfOffbits
Header structure size		biSize
File size including header and pallet		bfsz
Size of Image in bytes		biSizeImage
	$bfsz = BiOffbits + biSizeImage$	
	$biSizeImage = biWidth * biHeight$	

Table 5 shows the values as they are known for the digitized map provided. The two primary areas of difference are 1) the geographic location and orientation, and 2) the number and specification of colors.

**a. Geographic Problem**

Consider the geographic location first. The map contains easting and northing lines, which specify the geographic location. The central rotated rectangle in the left of the following diagram shows the geographic layout of the easting and northing lines in the current file.

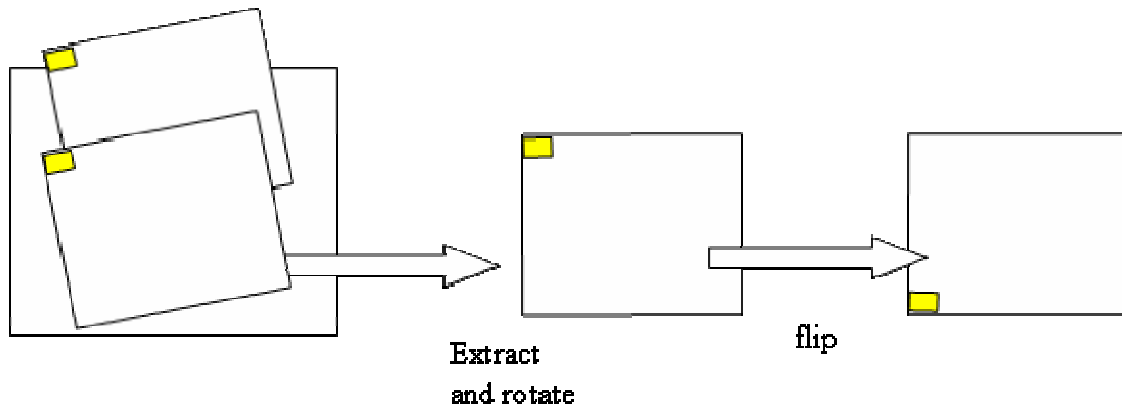


Figure 28. Image Correction Part: Extract, Rotate, and Flip.

The inner rectangle must be extracted, rotated, and flipped so that there is a file in which the first pixel is the lower left point of a known eeeeeeeE and nnnnnnN location and the size of the sides in both meters and pixels is known.

**b. Color Problem**

A blow-up of the digitized map shown on the left in Figure 28 shows the effect of anti-aliasing and dithering. White or gray regions, as well as lines, actually contain a large number of colors. These must be reduced to 16 colors.

Hence, a process is needed which will allow the operator to select a bundle of colors and assign them one of the 16 colors available.

Also, lines and sharp features whose corners have been aliased into other colors need to be eliminated and connected if gaps appear.

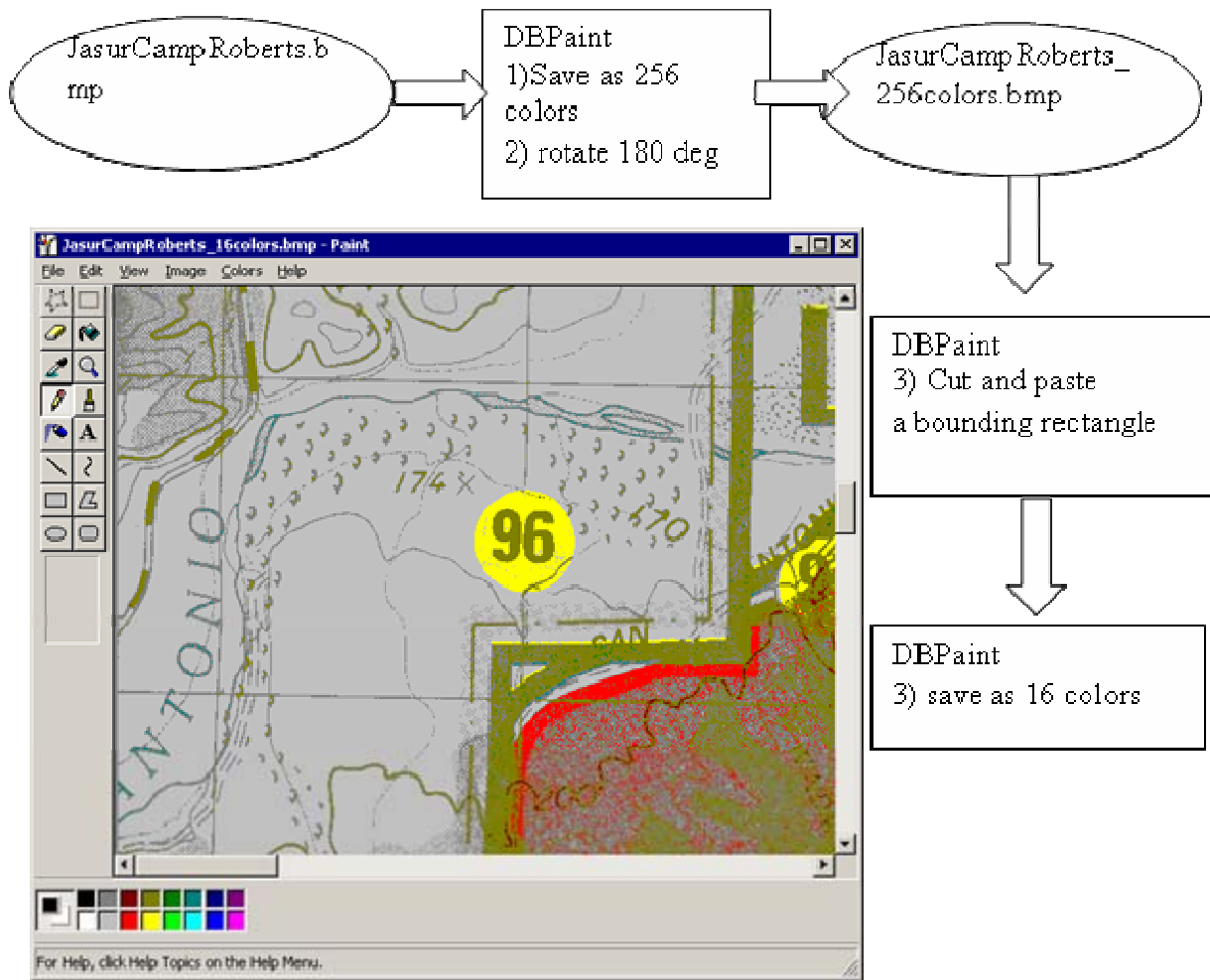


Figure 29. Processing Steps Using DBPaint.

It is possible to use the available Microsoft Office Picture Manager to rotate and crop the picture to fit an exact rectangle. This program also allows modification of saturation and hue to reduce the number of colors and make the map look better. Then, MSPaint is used to convert the image to a 4 bit color scheme.

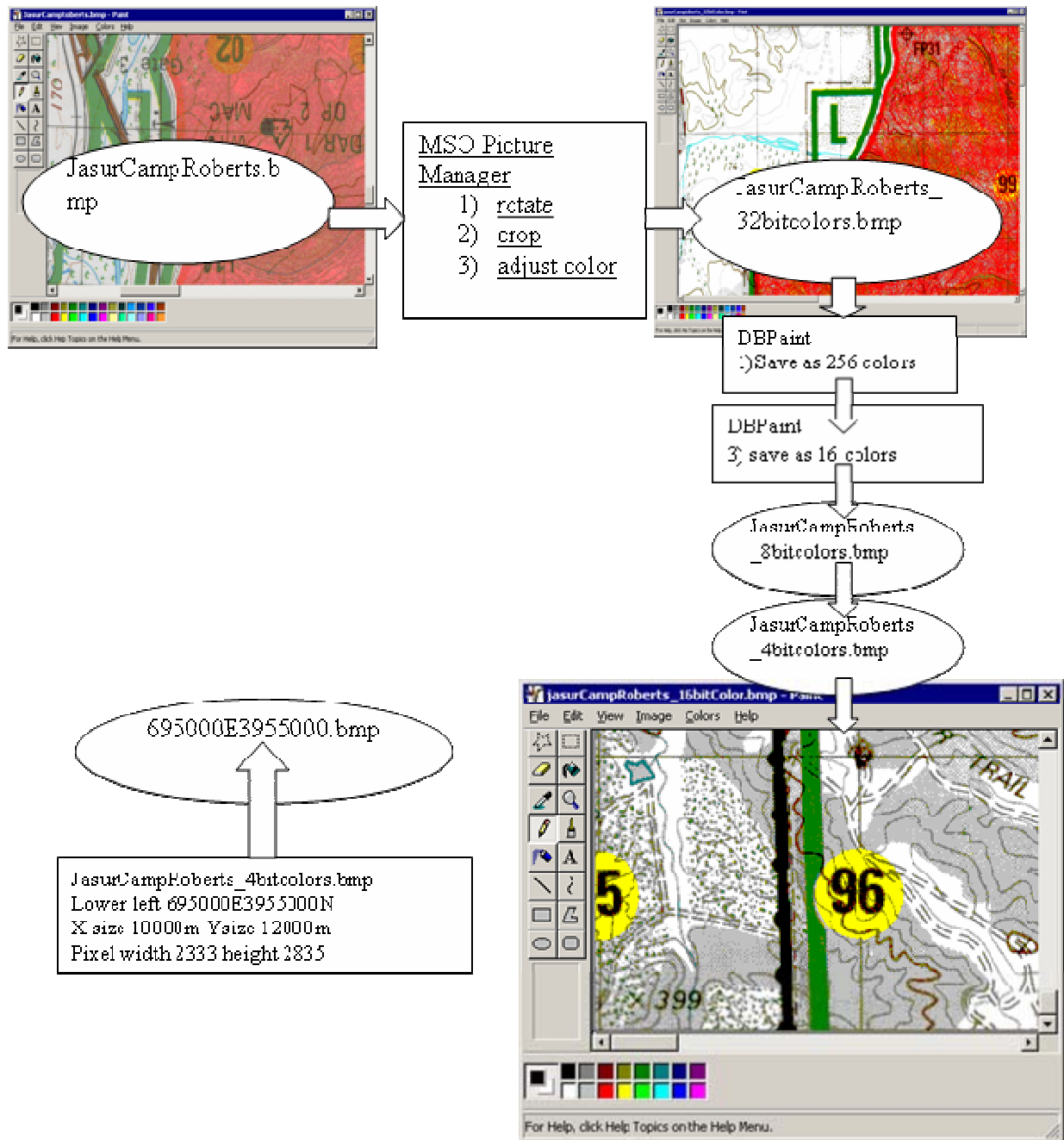


Figure 30. Processing Steps Using Microsoft Office Picture Manager and DBPaint.

Figure 30 shows the combined sequence of processing steps from the Jasur CampRoberts.bmp source file through the crop, rotate and color reduction steps, ending with a rename of the file to reflect its location. The last filename is N695000E3955000.bmp

In MSPaint, the *Image->Attribute* function provides a pixel count of 2333x2835 for this file. Now, use the data from the file to produce a metadata file containing the information required to retrieve and import the map. Lastly, the area to be loaded out of the available 10x12km area is selected. Figure 31 shows the dialog in PVNT used for defining the area from the import file to be used. Actual loaded areas must be 256 block boundaries.

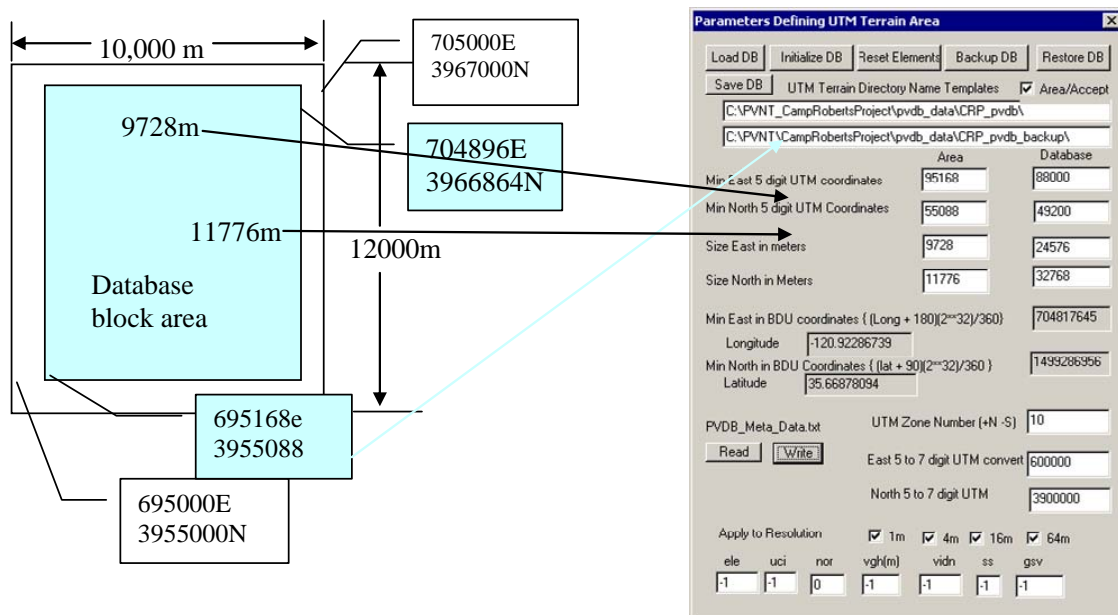
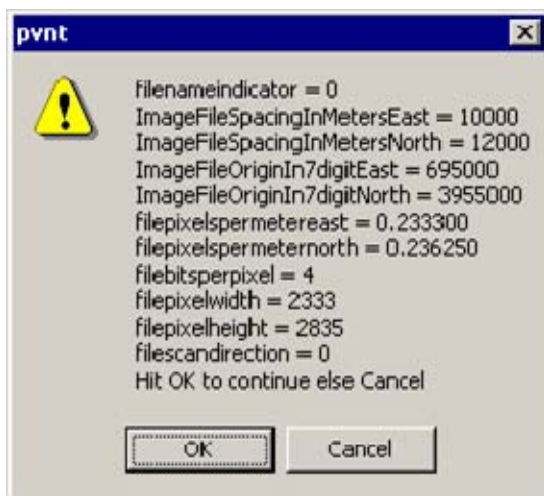
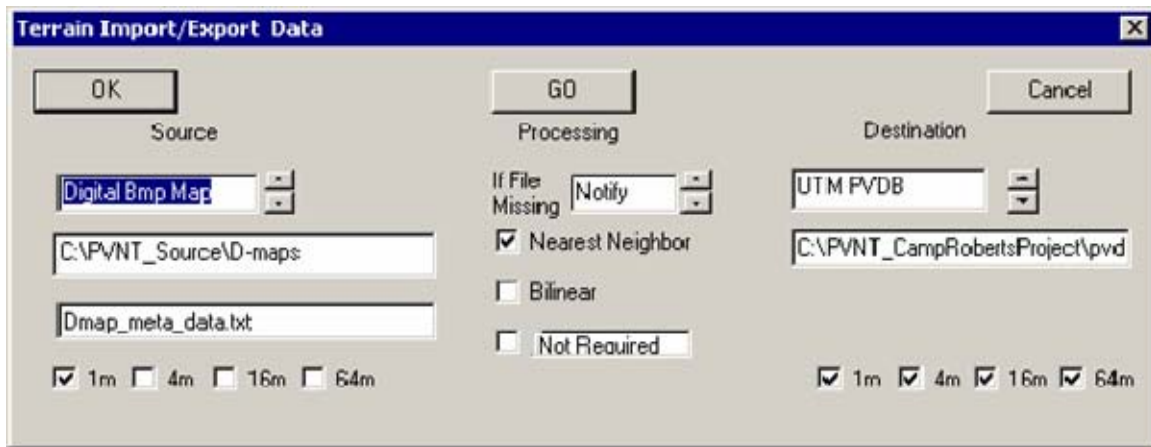


Figure 31. Parameters Defining UTM Terrain Area.

The shaded area shows the largest rectangle completely within the input file area, which can be made along the 256x256 block boundaries of the PVDB database. These are the values. The following is the run-time operational sequence for loading this map file. Run the PVNT and set the Area to be loaded as above. Then, set the import menu as follows.

In this test case, the data location is C:\PVNT\_Source\D-maps.

The meta-filename is Dmap\_meta\_data.txt.



Check the parameters PVNT reads from the meta data file to determine if the parameters are correct.

Hit OK

Figure 32 shows the Terrain Import/Export toolbar on the PVNT.

In this case, the warning shown in Figure 32 appears.

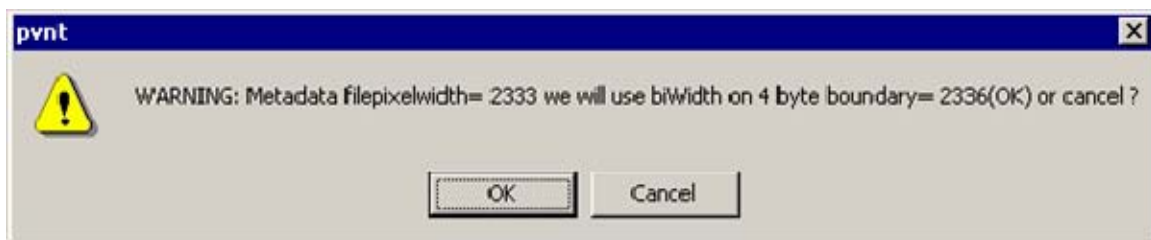


Figure 32. Terrain Import/Export Toolbar on the PVNT.

This warning occurs because there are 2333 actual pixels in the image width of the Bitmap file, but there are 2336 pixels in the file. The extra three pixels are required to make the file size equal to the 4-byte boundary data structure. The actual file size of the image is  $2336 \times 2835 = 3311280$  pixels. Hit OK or cancel and edit the file pixel width to 2336 to avoid the warning.

The result of this data load provides a good map background in the PVNT database, as shown in Figure 33.

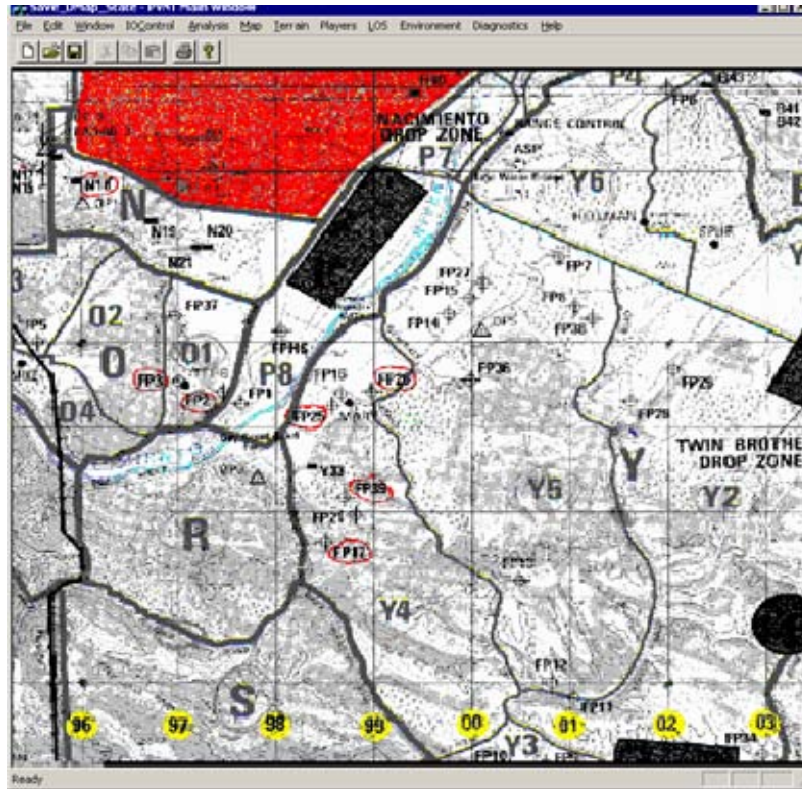


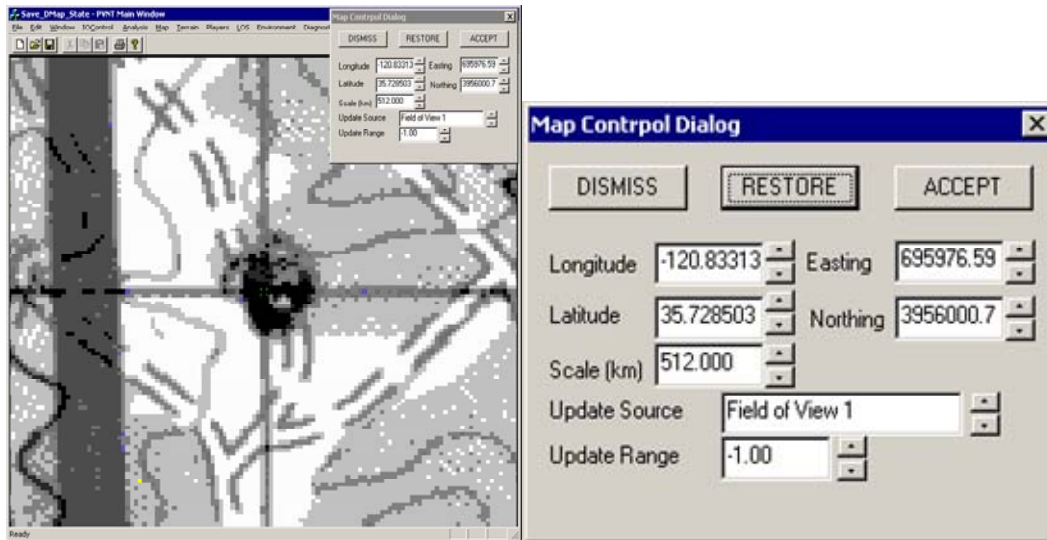
Figure 33. Camp Roberts PVNT Converted Map.

### c. *Geometric Accuracy*

During the pre-experiment, layering the topographic map into the Digital Elevation Terrain (DET) Database coordinate system incurred some problems with geographic accuracy with lower left and upper right corners. Moreover, changing the scale also resulted in geometric accuracy mistakes. For example, the first was measured with the 512 scale (see top image in Figure 34).

Lower left 696000E 3956000N

East error -24.4m E North error .7m N



Upper right  
704000E 3966000N

East error +24.55m E North error -11.5m N

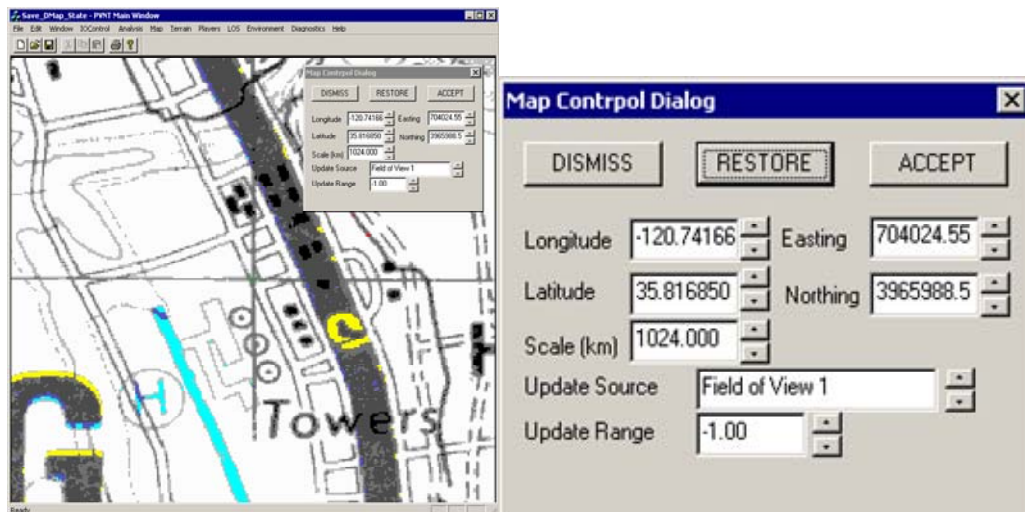


Figure 34. Map Controlling Dialog Toolbar - PVNT in Action.

It appears that the north-south scale is acceptable, but the east-west scale is off by 50 meters in the 10,000m span ( $50\text{m}/10000 = .005$ ).

Checking the pixel coordinates of these points in MSPaint LL 227, 2599 UR 2104,240.

Calculating the geographic distance using these values gives:

Easting Direction:

$$(2104-227) / .2333 = 1877/.2333 = 8045 \text{ meter}$$

$$(2104-227) / .2346 = 1877/.2346 = 8000.85 \text{ meter}$$

Northing Direction:

$$(2599 - 240)/.23625 = 2359/.23625 = 9985 \text{ Old}$$

$$(2599 - 240)/.23590 = 2359/.23590 = 10000$$

```
// FHDB Auxiliary Image, elevation, Dmap file for 695000E3955000.bmp
// format
// value parameter any comment you want
19778 ImageFileTypeMagicNumber // File type magic number BMP=19778, RAW=0
10000 ImageFileSpacingInMetersEast // distance the filenames and file content are spaced;area covered
12000 ImageFileSpacingInMetersNorth // distance the filenames and file content are spaced;area covered
695025 ImageFileOriginIn7digitEast //Lower left origing of the filenames
3955000 ImageFileOriginIn7digitNorth // Lower origin the filenames
.2346 filepixelspermetereast // half meter spacing of pixels
.2360 filepixelspermeternorth // half meter spacing of pixels
4 filebitsperpixel // bits per pixel in image
2336 filepixelwidth// pixels in the row or the x direction
2835 filepixelheight // pixels in the column or the y direction
00 filesdirection //00=raster lower left,01=raster upper left,10=caster lower left,11=caster upper left
```

Figure 35. PVNT Metadata File for Digital Map.

Changing the lower left hand corner of the file location by 25 meters, and changing the easting scale to .2346 meters and the northing scale to .2359, it should be possible to obtain a better match. It turned out that the .2359 correction was a bit too much, so it was changed back to .2360. Therefore, change the Dmap\_Meta\_Data.txt (Figure 35 shows metadata log file for Digital Map Data) and the filename to 695025E3955000N.bmp and rerun the import operation described above. A file size coverage warning appears because the pixel size was changed, but that is acceptable.

Now the lower left hand corner is at 695996.56 E 3956001.1N.

The upper left hand corner is at 703998.69 E 3966001.5N.

This represents errors on the order of 1 pixel =~4 meters, which are acceptable for this application.

This may not be the only error. One of the characteristics of digitizers is that the starting pixels in each row tend to be different because of inaccuracies in the timing circuits. This causes the first pixels to start at different positions, introducing a wobble in vertical lines. The size of this wobble can be measured by checking the x-pixel count along vertical lines. Figure 36 shows a PVNT Camp Roberts topographic map display. The white area shows the map overlay image. Both the edges and the vertical black Northing lines have a slight wobble.

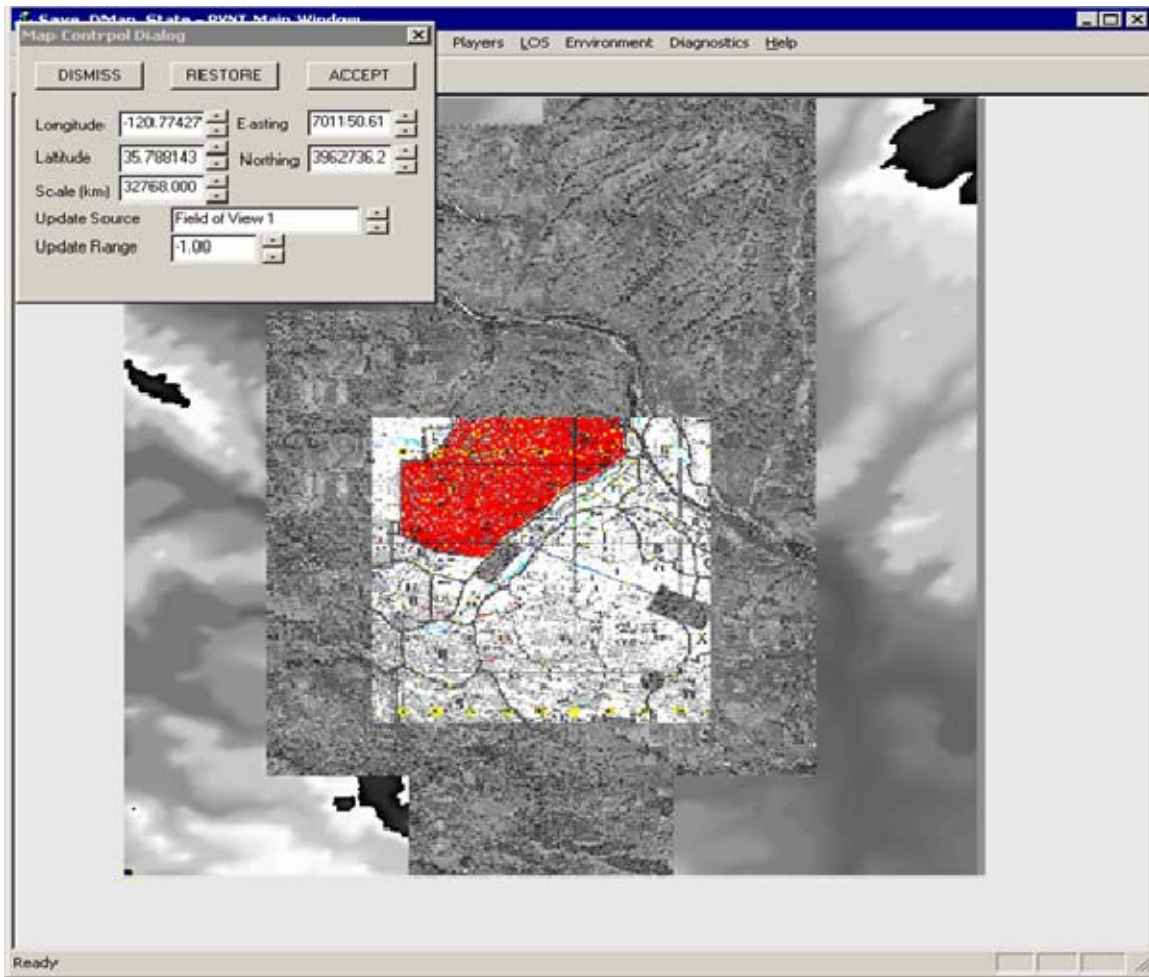


Figure 36. SA Camp Roberts Topographic Map Display.

## 2. Fort Hood Digital Copy Example

It is helpful to discuss how commercial data, such as the digital topographic maps used in this thesis, were obtained from the Internet. First, in order to use U.S. maps, we a member of an Internet map-selling company is required, such as [www.MapCard.com](http://www.MapCard.com). The membership fee is \$14.95 U.S. for a one-year basic subscription. Members receive a login ID and password for the one-year timeframe. Figure 37 shows the web site used during this thesis research to retrieve the necessary topographic maps. Members have access to all necessary digital maps and may use (download, copy, transfer) them. This online map server is very useful and is basically good for North America and especially the U.S.

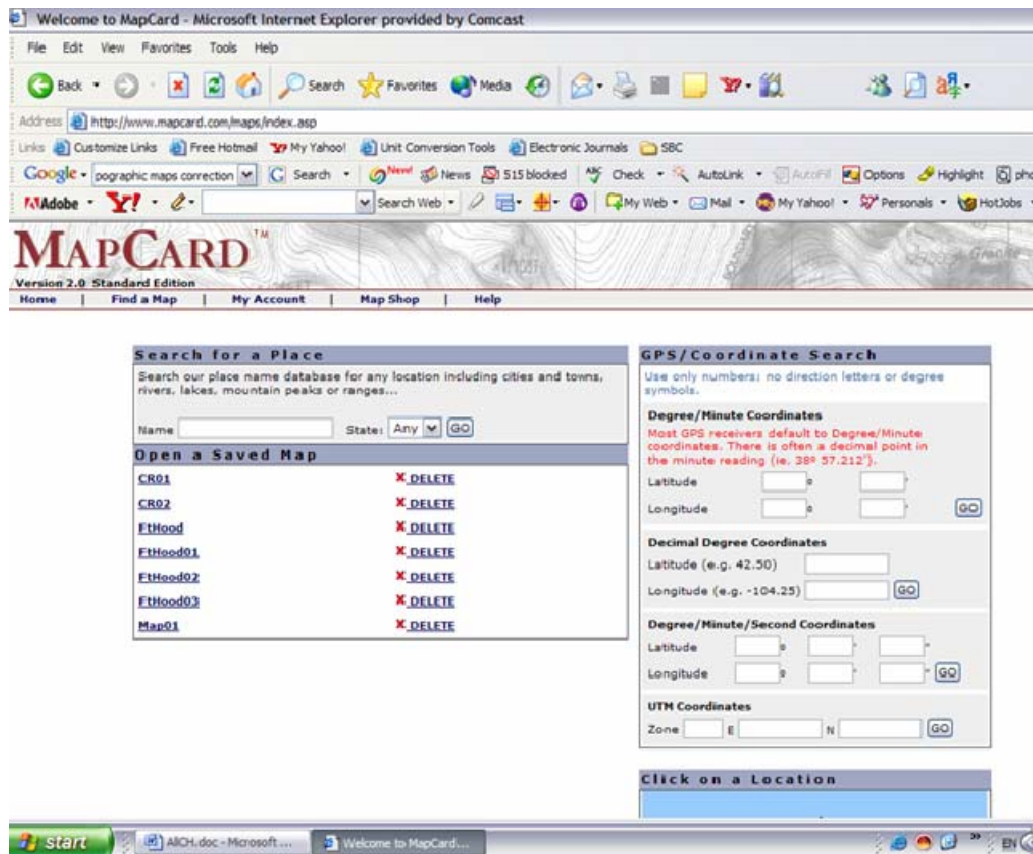


Figure 37. Example of Mapcard Site (From: Mapcard<sup>36</sup>).

A GPS/coordinate search of this site provides the image of the desired place and coordinate. Figure 38 shows GPS coordinates for Fort Hood.


Location: Lat 31.2040, Lon -97.6727	0  1 miles
State: Texas <a href="#">[more about this map]</a>	

Figure 38. Fort Hood GPS Coordinates in MapCard.

Moreover, users can simply enter the name of a city or state and a map will be provided. One advantage of this site is that there is an online database for members in which all map searches can be saved. This database allows users to save formats in

<sup>36</sup> Mapcard, retrieved October 2005 from [www.mapcard.com](http://www.mapcard.com).



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## **VI. TEST AND EXPERIMENTATION**

### **A. INTRODUCTION**

This chapter discusses field testing and experimentation conducted at Camp Roberts, California. The United States Special Operations Command (USSOCOM) and the United States Naval Postgraduate School (NPS) conducted the final quarter FY 05 cooperative Field Experimentation at Camp Roberts, California from August 29, 2005 to September 2, 2005.

The goal of the Cooperative Field Experimentation Program is to focus on identifying key gaps and deficiencies resulting from applications of advanced technology, particularly network communications, unmanned systems and net-centric applications. Special Operation Forces Joint 9 (SOF-J9) has assumed the lead with the Special Operations Acquisition and Logistics (SOAL) Advanced Technology Directorate to conduct leveraged experiments in cooperation with the NPS Field Experimentation Program.<sup>37</sup>

### **B. DESIGN OF EXPERIMENT**

The objective of this experiment was to investigate applications of advanced technology and networks in support of Special Operation Forces (SOF) missions. Specifically, the following experiments were conducted:

1. Investigation of advanced network performance as a function of wireless network backbone configuration.
2. Improvised Explosive Device (IED) Detection, Jamming, and Mitigation
3. Radio Frequency Identification Devices (RFID)
4. Collaborative and Situational Awareness Tools
5. Target Tracking, and Coordinate Mensuration Using Small Unmanned Aerial Vehicles (UAVs)
6. Light Reconnaissance Vehicle (LRV) – Initial Operation as Mobile Tactical Operations Center (TOC)
7. Direction Finding for High Value Target (HVT)

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<sup>37</sup> USSOCOM/NPS Field Experimentation Program Tactical Network Topologies 05-04 Report.

8. HVT Identification (Biometrics)
9. Human Systems Interface (HSI) / Human Factors Considerations

In the context of the Cooperative Field Experimentation Program, a team headed by Dr. Wolfgang Baer conducted experiments to test the remote operation, interface and effectiveness of the PVNT based Precision Targeting Mission Control Support System (MCSS) to support experiment 5 listed above (Figure 40).

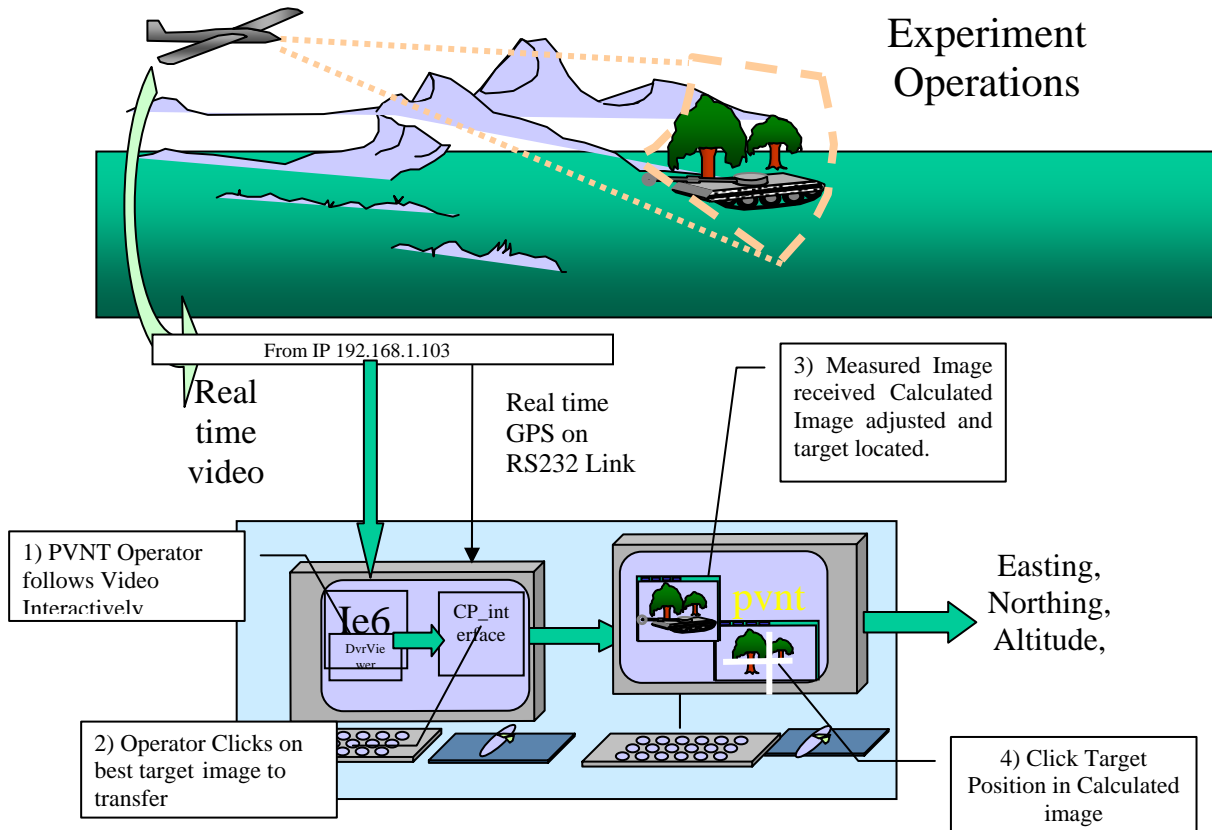


Figure 40. PVNT Based Precision Targeting MCSS.

The primary goal of this experiment was to establish connectivity between SUAV TOC and the NPS Gialab. The following sub goals were established from current research:

- Test and maintain connectivity through SUAV into the Tactical Operations Center (TOC) and Gialab PVNT system;
- Transmit video from SUAV into PVNT system, which was located in the Gialab and TOC.

- Effectively transmit serial data from SUAV into the TOC and Giga lab PVNT system;
- Test target mensuration at the Gigalab;
- Test the topographical layer in the PVNT system to adjust image based targeting.

This last goal specifically addresses the utilization of geographic map data previously placed into the PVNT Database as described in the previous section. During the TNT4-05 field experiments, PVNT achieved several experiment goals such as:

- Network connectivity was established between the SUAV - TOC Camp Roberts and NPS Gigalab;
- Voice communication was established between the TOC and Gigalab;
- Target mensuration test was performed at the Gigalab;
- Topographical layer was used by the PVNT system to effectively work with FMCSS and the image based targeting better.

The next section describes the general network capabilities provided while the subsequent section describes the UAV Target mensuration experiment in detail.

### **C. CAPABILITIES AND NETWORK BUILDING BLOCKS**

The SOF HVT search is a current operational activity. Convoy IED threat/attack is also a real and current problem for ongoing operations. A series of four scenarios were planned to investigate the application of three different communications links between deployed forces and the TOC to determine their effect on HVT search mission performance. The communication links affect situational awareness, the ability of the TOC to direct operations, and the time it takes to get HVT biometrics information to the deployed forces. Iridium, ITT airborne mesh using tethered balloons, and airborne 802.16/ Orthogonal Frequency Division Multiplexing (OFDM) using the Pelican surrogate UAV were the three communications methods to be compared.

The concept of a Light Reconnaissance Vehicle (LRV) was also introduced. This vehicle (2005 Toyota Tacoma) deploys with a SOF unit(s) to provide local C3I for the dismounted soldiers and global C3I for reach-back to the TOC. It has a telescoping antenna mast, real-time SA, network cameras, VoIP, network performance prediction and monitoring tools, and is a joint point for receiving and transmitting the utilized wireless signals from different networks to the TOC.

Dismounted soldiers will communicate with each other and with the LRV using a ruggedized Personalized Digital Assistant (PDA); in this case the INTER-4 Tacticomp which has two-way voice, video, and data. Real-time reach-back to the Biometrics Fusion Center (BFC) will be used together with a BFC “biometrics PC” to provide positive ID of a HVT. This is facilitated by the 802.16/OFDM backbone between the Camp Roberts TOC and the NPS Network Operations Center (NOC) (~100 mi) and a Virtual Private Network (VPN) between the NPS NOC and the BFC. The National Tactical Integration Office (NTIO) Digital Receiver Technology (DRT) will also be utilized for locating and identifying HVT.

The return leg of the HVT search mission involves a convoy IED threat. Several current and new technologies are being investigated to determine their effectiveness for reducing this threat. These include surveillance sensors, which use “resource aggregation” to provide the required bandwidth, smart rocks, RFID tags on vehicles, UAV SR using airborne ITT mesh network, UAV automated tracking and precision targeting, close-up IED inspection using a Morphing Micro Air-land Vehicle (MMALV) which can fly to a target and then crawl to/under it, and smart precision jammers.

#### **D. PVNT TARGET MENSURATION EXPERIMENT**

The target tracking experiment during the Tactical Network Topology experiment 4, 2005 (TNT4-05) period was primarily designed to test and checkout the connectivity, and interface message format integrity between field deployed NPS Small UAV (SUAV) and PVNT based MCSS located at the Gigalab on campus. Sufficient success was achieved to allow several image based targeting tests to be performed. This test verified the ability to transmit video and telemetry from a flying UAV to a remote site, perform a precision target location determination, and transmit the result back to the field in near real time.

Figure 41 shows the equipment and software configuration for the Gigalab target mensuration experiment conducted for TNT4-05. The NPS Small Unmanned Aerial Vehicle (SUAV) was flown by a team headed by Dr. Isaac Kaminer.

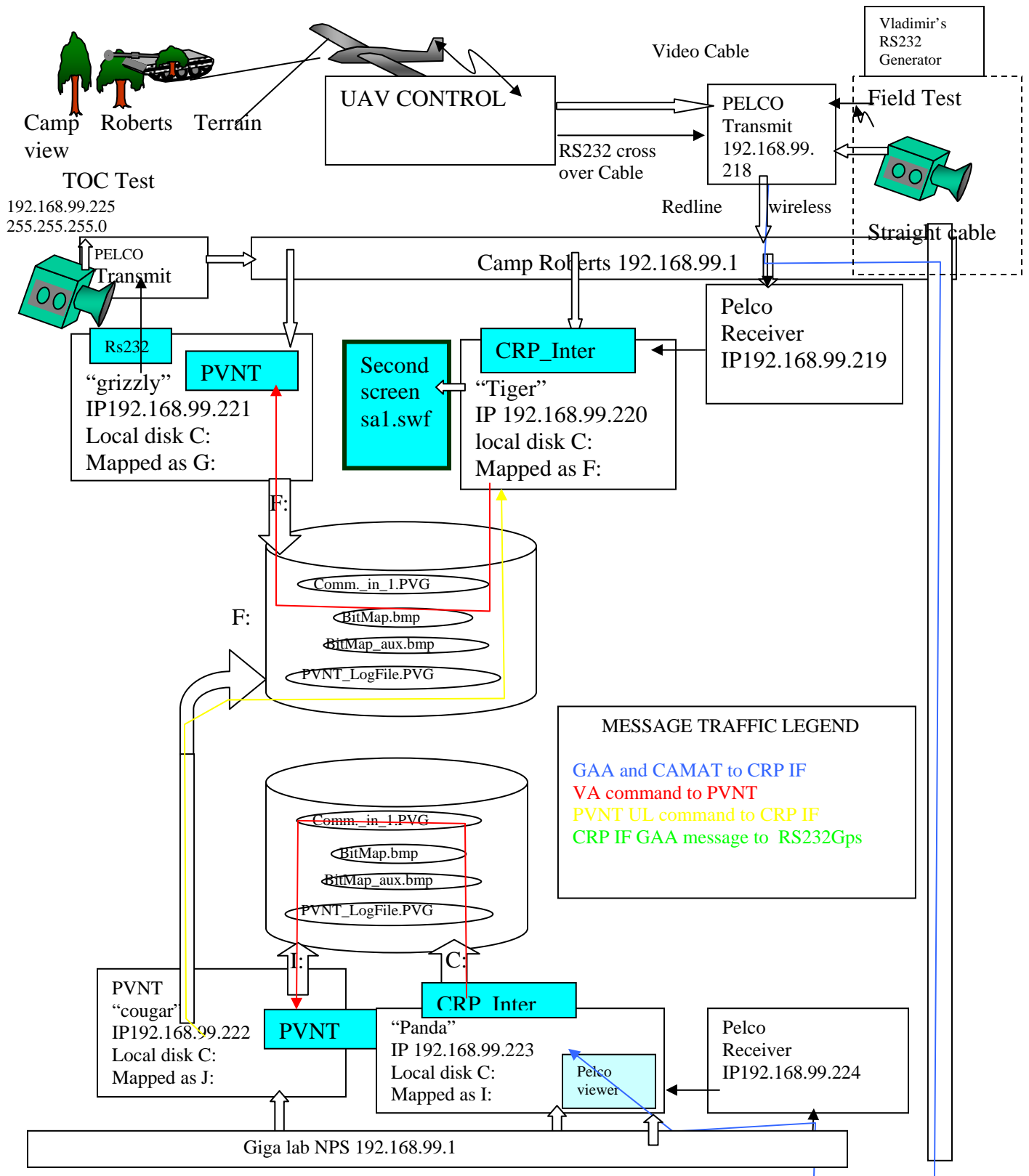


Figure 41. System Configurations' Experiment Conducted for TNT4-05.

The NPS SUAV is a small UAV (commercial, low cost) which has a Piccolo flight control and a pan-tilt-zoom camera. The flight control and camera are linked to provide the ability to lock the camera on a moving or stationary target, keeping the image in the center of the screen. It also provides target coordinates to within about 20 meters. This information is passed to the PVNT software (located remotely at NOC/NPS through TOC Camp Roberts, California) which provides near-real-time 3D terrain image subtraction; giving the target coordinates to within 1-2 meters. The SUAV is fully integrated into the Tactical Network and SA.<sup>38</sup> The UAV was then flown in patterns around the air strip.

The GPS coordinates of several targets, consisting of two automobiles and several parked vehicles in the parking area approximately half way between the UAV control tent and the TOC, were recorded. The UAV was then flown in patterns around the air strip. The video from the camera along with the GPS latitude, longitude, altimeter altitude and UTM coordinate referenced camera pointing angles were transmitted to the Tactical Operations Center and to the Gigalab (see blue line in Figure 41). At both sites, the information was ingested by an HP 2.8 Ghz PC outfitted with a Pelco Viewer and the CR\_interface program that captured and displayed six seconds of images each at one second intervals and synchronized the image with telemetry messages. At both locations, the messages were also relayed to a second computer running the PVNT software to generate telemetry-controlled calculated perspective views. This second computer received GPS and camera angle coordinates at one-second intervals.

The Gigalab operator would watch the incoming live video on the interface computer called "Panda". When the aircraft flew over a target point that could be recognized, the operator would watch the captured image with the recognized target transferred through the six trailing frames who would then click the image transfer button on one of the trailing frames. A one second capture rate is about as fast as the operator can respond. This transfers the image to the PVNT machine along with the accompanying

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<sup>38</sup> USSOCOM/NPS Field Experimentation Program Tactical Network Topologies 05-04 Report.

best guess UAV position and camera angles. This information generates a green best guess image outline on the PVNT situational awareness display (see Chapter VII, Figure 42).

Due to errors in GPS and camera angles, the result of this transfer does not automatically provide a calculated view containing the target features. However, the position and angles are now accurate enough so that some identifiable features are usually within both the measured view from the UAV and the best guess view calculated from the telemetry. The PVNT operator manually performs a calculated view adjustment. Several mouse controls and image differencing algorithms are available to help this process. When the calculated and measured view are close enough to perform target location, the PVNT operator then performs a final target location by clicking on the location in the calculated image where the target would appear if it were in the database. The display generated on Tiger is placed on the second monitor output for display on the large wall display as shown in Figure 42.

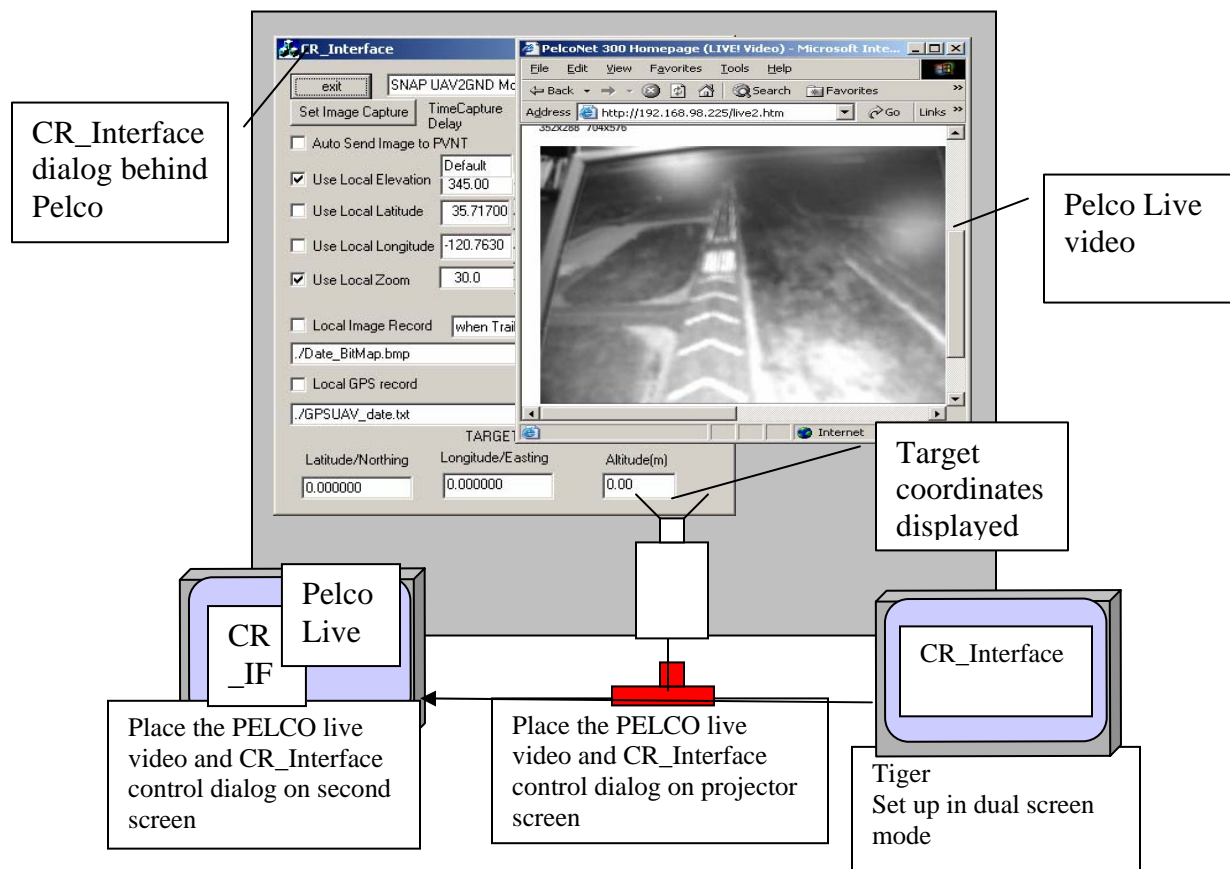


Figure 42. Target Coordinate Wall Display at the TOC.

The TOC provides network monitoring and management, real-time collaboration with external sites, collection of data for network modeling, and is the hub for situational awareness (SA) display. The SA tracks and provides the live display of all blue forces and sensor information.

#### **E. SUMMARY**

Chapter VI described test and experimentation conducted at Camp Roberts, California. In the Design of Experiment section, the general objective of the experiment was given. Moreover, the primary goals of the experiment were set. The section on Capabilities and Network Building Blocks discussed general network capabilities. The PVNT Target Mensuration Experiment section detailed the UAV Target mensuration experiment.

## **VII. RESULTS OF EXPERIMENTS**

### **A. UAV FLIGHT AND PRECISION TARGETING MISSION CONTROL SUPPORT SYSTEM**

#### **1. Summary of Results**

This chapter provides detailed features of the PVNT test conducted at the TNT4-05 field experiment. This experiment verified the ability to transmit video and telemetry from a flying UAV to a remote site, perform a precision target location determination, and transmit the result back to the field in near real time. Moreover, it clarified sufficiency of the image based targeting system. Detailed objectives and accomplishments are summarized below.

#### **2. General Thesis Experiment Overview**

The PVNT team developed a digital topographic map layer for the image based targeting function of the PVNT system. The benchmark for success in the PVNT system operation was based on digital map data layered on the Digital Elevation Map.

#### **3. SUAV – TOC – Giga Lab Network Establishment**

The network consisted of a camera mounted on the SUAV, sensors, wireless data relays, cables, switches, Pelco receivers, and transmitters; also a bridge connection was used to establish connection between the SUAV support group and TOC. Through the established network, the ability to receive video imagery, GPS location, and camera attitude parameters from the field during flight was verified at the TOC, and these parameters were transmitted through the network into the Gigalab. During the experiment, the ability to transmit imagery and telemetry data to the PVNT station located at the Gigalab for target mensuration was demonstrated. Moreover, the ability to receive video imagery, GPS location, and camera attitude parameters from the field during flight at the Gigalab at NPS was demonstrated. Also, the ability to display UAV, camera field of view and potential target location on the new map based situational awareness display (see Figure 42) was demonstrated. The main achievement of this experiment was the ability to determine target position to approximately one meter accuracy.

Moreover, this provided target icon, view cone, and UAV icon display on the SA map, and image map as selected by the operator. Using the network succeeded in demonstrating stationary target location capability, and the following results were achieved:

- Near real time( ~ 10 sec) accuracy on the order of 1 to 2 meters for permanent structure (rear door of TOC)
- Near real time( ~ 10 sec) accuracy on the order of 5 to 10 meters for double truck target in parking lot. Due to some distortions on the transmitted video from UAV, changed features such as new pavement and additional parked cars had limited accuracy.
- Non real time (1 to 2 min) accuracy 2 to 5 meters using PVNT image difference technology.

This setup (Figure 42) shows the live PELCO video along with the PVNT mensurated target coordinates as shown on the wall display at the TOC.

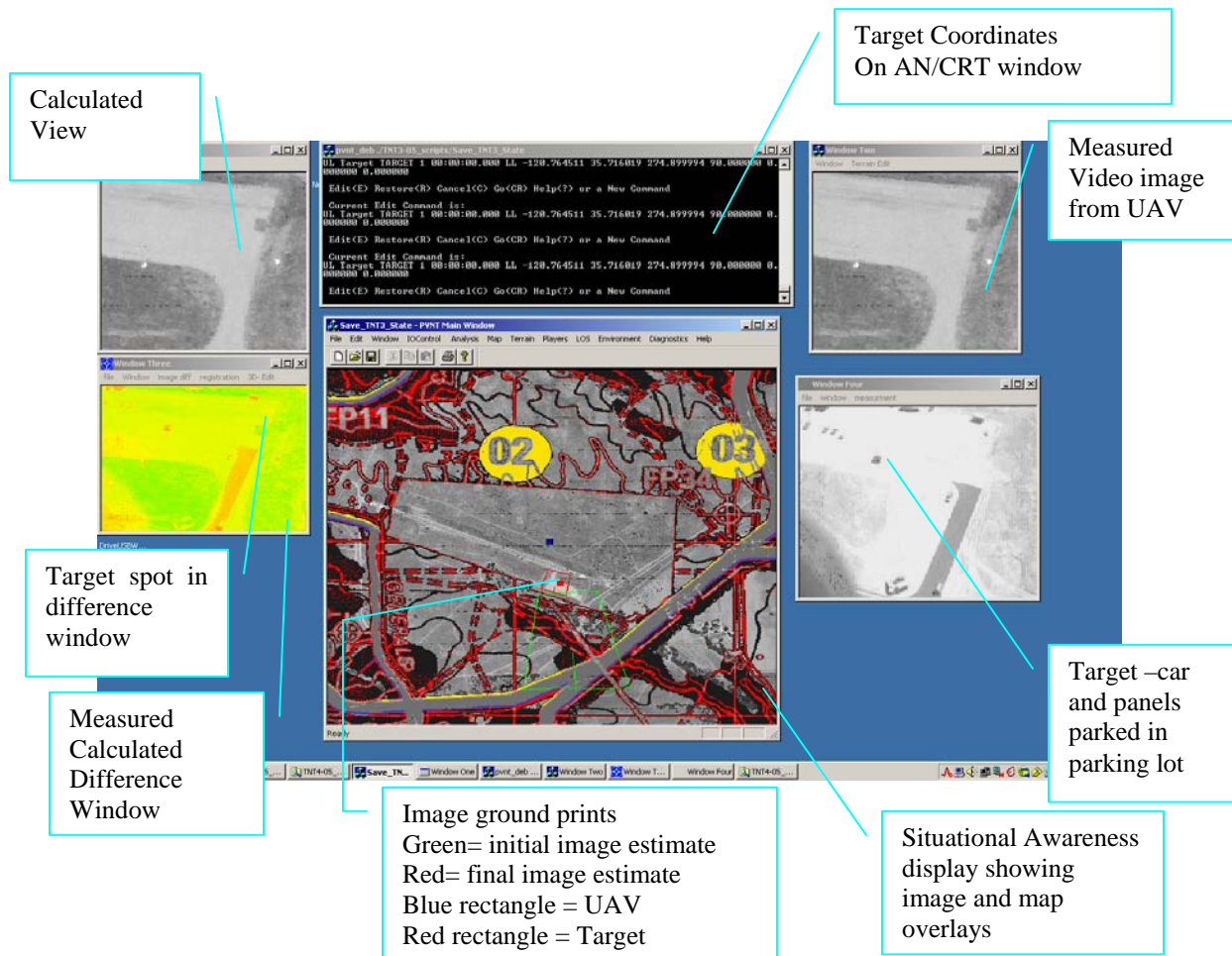


Figure 43. PVNT Situational Awareness Display.

Lastly, the calculated target coordinates were also transmitted from the Tiger interface machine to the “Grizzly” machine running the PVNT SA map display. Figure 43 shows icons for the UAV (blue square) and the newly identified target (red square). A screen capture of the map display is shown in Figures 43 and 44. These map displays show red topographic map overlays recently added to the PVNT display. The main idea of this experiment was to use this layer for image based targeting. Also, this layer may be used to measure the distance between the objects accurately, or to perform path finding or route searching analysis. The difference between the two map displays are the levels of image allowed to merge with the topographic map display. PVNT currently allows two map colors to be identified as transparent in order to allow image features to “shine” through. On the pure map display shown in Figure 43, the entire McMilan air strip is colored black and does not show details available in the overlay view shown in Figure 43.

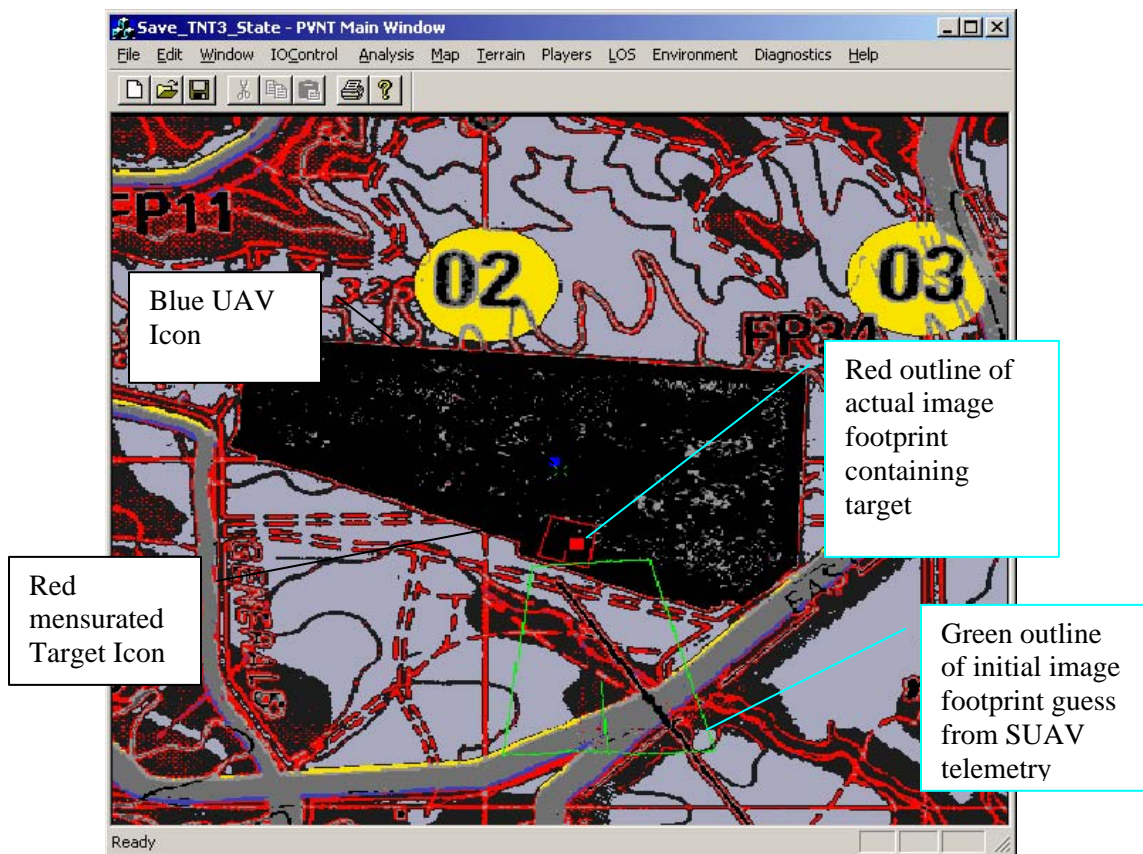


Figure 44. Pure PVNT Map Display of UAV and Target Icons.

Note the situational awareness display shows the map data added as the result of this thesis. The utilization of map overlays allows the result of calculations, in this case target coordinates, to be displayed on a map familiar to military personnel.

#### 4. Near Real Time Results for TOC Back Door

Figure 44 shows a copy of the calculated, measured and map views available at the instant of target location for the TOC BackDoor position determination. The green rectangle shows the initial best guess at the instant of capture, while the red rectangle shows the adjusted view. This was an exercise test, since at the time, no target had been designated and the desire was to mensurate something. Note also the Instant Messenger program running. This provided voice communication between the TOC and the Gigalab.



Figure 45. Image Capture in 10 AM Flight Wed. May 25.

After the PVNT mensuration of the TOC back door, the GPS location of this feature was measured with Dave Netzer's GPS receiver. The results are shown in Table 5.

Table 5. GPS Target Location Experiment Data.

Data received from	Coordinates in Longitudes	Coordinates in Latitudes
Determined by PVNT	120.763885	35.715492
GPS measurement	120.45.5	35.42'56.
Converted	120.76386	35.71551
<i>Delta in degrees</i>	<i>.00002</i>	<i>.00001</i>
<i>GPS vs PVNT delta</i>	<i>2.2 m</i>	<i>1.1m</i>
Time ~ 10 seconds		

## 5. Near Real Time Results for Double Truck

The HVT was identified as the double truck by voice description from the TOC. The operator clicked the image trail at the Gigalab and started target mensuration. The calculated camera view was turned toward the field and a position clicked near the grass curve in the calculated image. This took approximately 10 seconds. Position determination was performed purely by operator recognition and estimation. While Figure 45 shows how the PVNT operator identified the target, Figure 46 shows that operator clicked on the calculated image window in order to locate the target position in GPS coordinates.



Figure 46. Measured Image



Figure 47. Calculated Image

Table 6 shows a comparison of the results for this determination.

Table 6. Comparing Results of PVNT and GPS Coordinates.

Data received from	Coordinates in Longitudes	Coordinates in Latitudes
PVNT	-120.764336	35.715954
GPS	120.76456	35.71603
Delta degrees	.00023	.00008

The poorly captured image quality and lack of distinguishable terrain features made the initial near real time position determination uncertain (See Figure 48). The only feature available was the grass curve and the double truck looked like it was close to the grass curve shown in the measured image shown in Figure 47. This feature's misidentification caused a large east-west error.



Figure 48. Measured Image Display.

## 6. Differencing Correction Result for Double Truck

The next processing step was to use the difference window (marked in yellow) in Figure 49 to perform a more accurate calculated and measured image registration. The following screen capture shows the PVNT with a live video captured image on the top, the best calculated view on the upper left, and the differencing view on the middle lower left. What can clearly be seen is that a new tarmack feature had been constructed since the database was built. The blooming in the measured image eliminated all features close

to the new construction. Thus, the operator took the only two common points on the upper left of both the measured and calculated image as points of registration and rotated the difference image until the new feature lined up with the grass edge along the right side (Figure 48). The target then clearly shows up substantially left of the grass curve used in the previous near real time mensuration described in the last section.

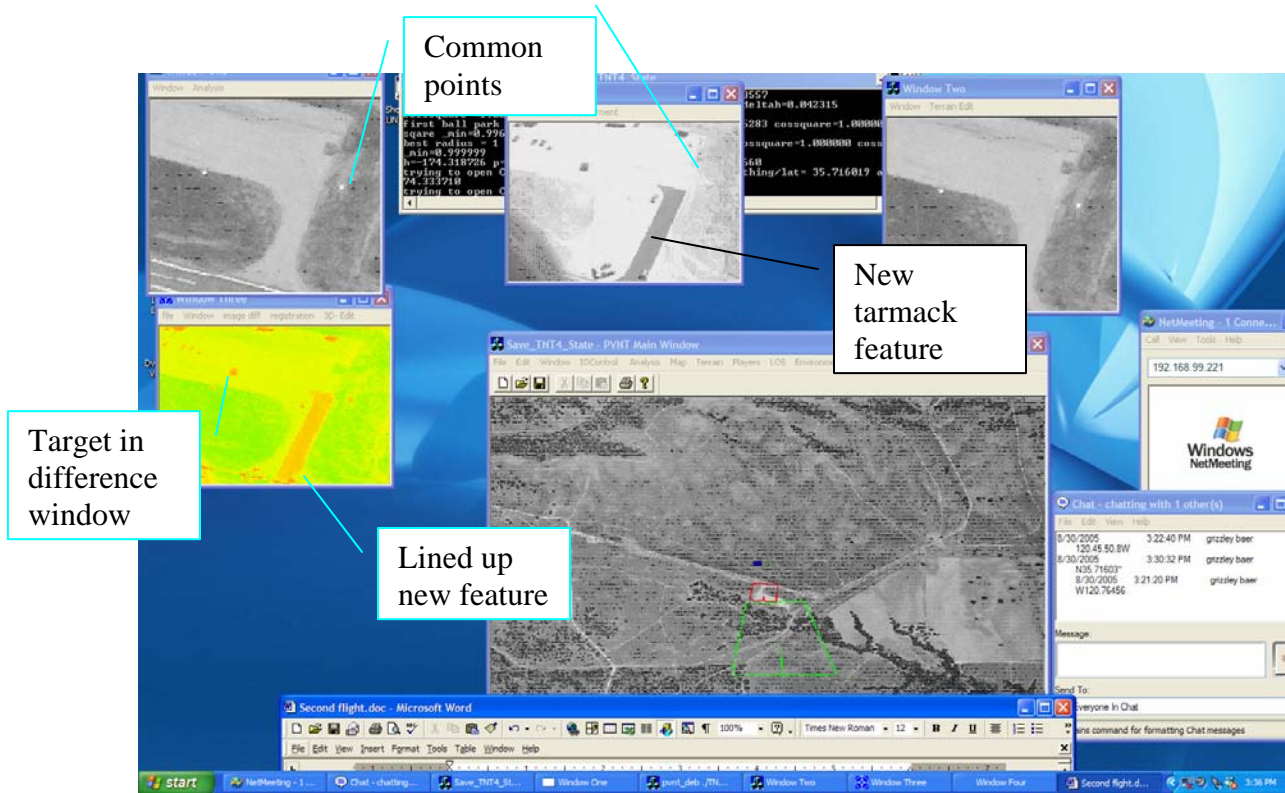


Figure 49. Image Correction Display.

Using the difference window, the target error is reduced to 5.5 and 2.2 meters (Table 7) but the process cost about two minutes.

Table 7. Comparing GPS Data with PVNT Output.

Data received from	Coordinates in Longitudes	Coordinates in Latitudes
PVNT	-120.764572	35.715893
GPS	120.76456	35.71603
<i>Delta degrees</i>	<i>.000012</i>	<i>.00014</i>
<i>Meters</i>	<i>5.5</i>	<i>2.2</i>

The above experiment shows the importance of image differencing to register measured and calculated images properly. Any image from the field can be mensurated as long as terrain features can be recognized. By selecting an easily seen feature, this recognition challenge is largely eliminated. The experiment demonstrates that image based targeting can be done with very low cost equipment on the UAV since only the image is used. The UAV does not require accurate location or pointing gimbals for this technique to apply.

## **B. SUMMARY**

Chapter VII discussed detailed results of the PVNT test conducted during the TNT4-05 field experiment. The section on UAV Flight and Precision Targeting MCSS described the thesis experiment. Also, this section provided information about SUAV – TOC – Gigalab network establishment. Moreover, this section showed comparative analysis of Near Real Time Results for Double Truck GPS coordinates measurement and its differencing correction.

## VIII. CONCLUSION

### A. LESSONS LEARNED

The primary purpose of this thesis was to conduct the research necessary to develop integrated 3D terrain maps capable of supporting UAV FMCSS. Two types of problems were encountered during this research: pre-experiment problems during map data preparation and field experiment problems. These problems are described below.

#### 1. Pre-Experiment Problems

The present thesis research encountered some problems during pre-experiment preparation. These problems are briefly described below.

##### a. *Map Editing and Validation*

This thesis research encountered problems with map editing and validation. Desktop scanners are not designed for precision digitization. Ordinary desktop scanners introduce problems with scanned maps, such as scaling errors making the map appear squashed, flipped, or skewed. In order to eliminate these problems, some converter tools were used, as described in Chapter V. After-scan corrections were time consuming and difficult. A more professional approach is to use a drum scanner. These are most commonly used for maps. This type of scanner clamps maps to a rotating drum and scans the map with very fine increments of distance, measuring the amount of light reflected by the map when it is illuminated, with either a spot light source or a laser.<sup>39</sup>

##### b. *Internet Digital Map Search*

Chapter IV illustrated that there are different web sites that maintain digital topographic maps. As the digital topographical map data become more available, this source of data will be given more emphasis. More computer-based tools will be necessary for searching and browsing digital topographic data. Most of the Internet search tools only perform general searches. For example, by using the Google search engine and typing the word “image”, 430,000 results are obtained (on 9 November 2005). Therefore, it is necessary to use special search engines to help find and filter special

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<sup>39</sup> Keith C. Clarke, “Getting Started with Geographic Information Systems,” Prentice Hall, 2003, p. 110.

characteristic data. Moreover, there are different scales and topology, and most of the open source web sites do not have full databases of digital maps of the earth. Altogether, the job of finding the right map on the web is very time consuming.

## **2. Field Experiment Problems**

The transition from a laboratory environment to a field operation requires a level of ruggedness and detailed operational proficiency that is hard to come by without considerable effort. Comments for future guidance are discussed as follows.

### ***a. Equipment and Interface Reliability***

Specifically, the RS-232 links in new PC's requiring USB intermediate conversions tend to hang and require frequent resets. Additional programming has made these more rugged than experienced in TNT05-3. However, plugging and unplugging cables will send erroneous messages and all possible errors have not been handled by the CR\_Interface program. In fact, it is not even know what errors will be encountered until after such experiments are performed. Further testing and program ruggedization will be necessary.

### ***b. Network***

The network generally performed well. Occasional delays caused performance uncertainty and increased stress but no major network problems were encountered once things were up and running.

### ***c. Pelco Units***

The Pelco units also performed well although they are unreliable and difficult to program and learn. Experimentation showed that two transmitters can interfere and require power resets. Thus, it was difficult to inject a test signal as planned. After power reset, the units tended to couple with receivers and stay coupled. How they work is still rather unknown and they are difficult to set up. It would be a good idea to eliminate the RS232 communication requirement in favor of the Ethernet. Also, the Pelco unit's video transmission appears to interfere with the Net Meeting voice transmission so these could not be used on the same machine.

### ***d. Voice Communication***

Voice communication between team members when operations take place at remote locations is critical. The Voice-Over-Internet-Protocol (VOIP) phone system

from the Gigalab did work but was hard to use and could not be tested to generate confidence prior to the experiment. Net Meeting worked with the above mentioned interference. It would be a good idea to obtain a camera/voice equipped reliable personal presence machine on site to allow remote monitoring of field activities.

*e. Automation and Image Quality*

Video signals vary greatly from one UAV to another and between flights. Accommodating these variations has in almost all circumstances required a man in the loop. Automation means a level of control which is illusive in this experimental environment.<sup>40</sup>

**B. FUTURE RESEARCH**

This thesis provides tremendous opportunities for future research and development. In this section, some of these opportunities are presented and discussed.

In order to make an automated open source search engine, it would be useful to hyperlink all spatial databases and use them in one search key algorithm. Modern cartographic databases consist of different digital topographic types of maps. Some of the differences are scale, resolution, format, theme, features, and data structure such as arc/node (vector, raster). In order to build this algorithm, each topographical type for scale, resolution, and format should be analyzed as done before for interoperability with PVNT and other systems. One search engine prepared for the PVNT web site used a local web page search capability. In the case of this thesis, this local search for a number of web pages or web based spatial (digital topographical) databases should be implemented. Moreover, this search engine has to be automated to search according to some parameters of digital maps and called an image-based search engine, which allows an operator to find necessary layers quickly and more accurately. This will help to automatically combine necessary parts of maps and generate general views of the required environment.

Develop an automated search engine that will automatically qualify necessary topographic maps from the Internet, including the resolution of maps, editing and other

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<sup>40</sup> UAV Flight and Precision Targeting Mission Control Support System Experiment Results for TNT05-4.

required features that may be introduced. The Internet and the WWW provide users with unprecedented access to open source information resources. Data libraries make it possible to search for information on the Internet and locate it using simple tools. Possibilities of open source Internet data are very promising, but sometimes it is hard to unify this information into one standard. For this reason, the development of automated search engines, which will create links among Internet libraries and unify digital topographic data standards, is needed.

Conduct research and analysis on how to create a path finding algorithm using the PVNT map layer in order to calculate rational distance between two or multiple objects. The main idea is to create an optimal route between high value targets like an enemy object and intelligence group or platoon, or between multiple objects and groups. There are several criteria to implement path search approaches such as the shortest distance in the urban environment, the line of sight vision path, the direct path between objects, the path algorithm according to earth elevation, and situational awareness. This algorithm also could be used for multiple targets. This path finding research can be useful for intelligence or tactical groups on how to obtain target in a useful and quick way.

Develop the PVNT software tool to assist UAV operators in target tracking features and to calculate GPS coordinates for given objects and moving targets. The UAV flight support group has target locking and tracking features. It would be excellent to develop a network application that implements this feature both on the UAV flight support group and the PVNT in real time. In order to perfect the development of multiple UAV algorithms, a test environment that provides realistic imagery of moving targets is required. The construction of a Multi -UAV Target Tracking Test System based upon the PVNT software is proposed.

Develop embedded training systems to promote skill acquisition and maintenance using the PVNT as the training simulator. Such a system will be very useful for simulating UAV flight in order to develop accurate target tracking features. The PVNT embedded training system can provide an immersive simulation capability for a PVNT operator.

## **C. SUMMARY**

In this work, the author has explored the feasibility of exploiting digital topographic maps to augment the digital terrain support available to UAV FMCSS developers. Moreover, this thesis specifically explored and provided interpretation methodologies for topographic maps required to implement the UAV experiments. In Chapter II, the author presented some background work and discussed basic digital topology concepts. Also discussed were concepts in general and how specifically these relate to the research. In addition, several formats available to the military and civilian developer were illustrated.

Chapter III surveyed the requirements for an UAV flight and mission control system. The author provided a description of necessary characteristics, formats, and data criteria. Also, the author described in detail UAV control system conceptual characteristics, and how these characteristics would be implemented with the PVNT system. Last, the author specified necessary data requirements to support the UAV FMCSS.

Chapter IV described the mainstream data representations and formats available to the military and civilian developer. It also discussed common data representations, the availability and ease of use of each data representation type, and the organizations involved in developing the mainstream common terrain data formats. Moreover, this chapter presented references on geospatial information on the web and partially made it possible to access various maps and topographic images easily. It described the NPS Map Collection relevance to this thesis by showing some sample blocks from this web site and describing them in this chapter. The author conducted research for World topographic maps or open source maps and provided a reference table on the Global Map topographic sources.

Chapter V described the preliminary steps required to retrieve and convert source data identified in the last section to input files required by the PVNT program. It showed some examples of format conversion and data correction tools such as Image converter, Paint, Photoshop, and Microsoft Office Picture Manager. Two specific examples of data retrieval conversion and correction were given. The first utilized a digitizer to generate a

BMP format for Camp Roberts, California; the second used an Internet source to generate files for a test site at Fort Hood, Texas.

Chapter VI described the experimental set-up for this thesis to validate the use of the 3D maps for UAV FMCSS. Also discussed were experiments conducted to test the remote operation, interface and effectiveness of the PVNT based Precision Targeting Mission Control System Support (MCSS). The first part of the chapter described specific examples of the PVNT Target Mensuration. The second half of this chapter specified capabilities and network building block characteristics.

Chapter VII explored the results of the experiment conducted at Camp Roberts, California and provided a description of the specific configuration for the Gigalab target mensuration experiment conducted for TNT4-05. First, it described network connectivity established between the SUAV - TOC Camp Roberts and NPS Gigalab. Second, it characterized target mensuration tests performed at the Gigalab. Third, it described the topographical layer used by the PVNT system in order to work with FMCSS and the image based targeting test efficiently. This is the main idea of the present thesis experiment. This layer was used for the display of image based targeting results. It also provided tables summarizing successful and unsuccessful results of experiments.

Chapter VIII briefly discusses the conclusions drawn from the results of the proof of concept study along with some future discussion on the research and how to improve it.

The research successfully showed methodologies and the process of integrating some topographic 2D maps into a 3D battlefield visualization system. The author's vision is to be able to find, convert, and merge 2D maps into a complete high-fidelity effectiveness of the 2D terrain maps to display 3D target were achieved through available terrain map products. Several conversion tools to convert terrain maps into the PVNT compatible format were tested and described. This work described both a tool and design methodology for an analyst to utilize high fidelity data sets. Moreover, detailed UAV control system characteristics and necessary data requirements described implementation with the PVNT system. This whole research methodology was tested on thesis field

experiments at Camp Roberts, California, where some image based targeting tests were simulated with the NPS SUAV system. Finally, based on the thesis research and experiments, some future research recommendations were given.

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